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Stress Analysis and Structures (7)
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Cables, Aircraft control - Fatigue failure (14701.2)

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O.S.R.D. 4819

The corrosion-fatigue failure of aircraft control cables (N-101)

O.S.R.D., N.D.R.C., Div. 18, Washington, D. C.

U.S. Eng. Restr. Feb '45 60 photos, tables, diagr, graphs

The physical properties of aircraft control cables were investigated under test conditions designed to reproduce the effect of service conditions. Cable materials included 18-8 stainless steel and bright, galvanized, tinned, and lead-alloy-coated carbon steel. Results of fatigue tests with 1% loads showed that under the severe corrosive conditions of a salt atmosphere and at -65°F, 18-8 stainless steel cables were the most effective. The tinned cables had the lowest internal friction in the absence of corrosion.

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NATIONAL DEFENSE RESEARCH COMMITTEE

of

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR METALLURGY DIVISION

File #819
Div. 18.

Final Report

on

THE CORROSION-FATIGUE FAILURE OF AIRCRAFT CONTROL CABLES (N-101)

by

DARTREY LEWIS, A. H. FLURY, JR., AND R. J. GODFREY
JOHN A. ROEBLING'S SONS COMPANY

Code No. ____

Serial No. M-457

Copy No. ____

February 26, 1945

February 26, 1945

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Final Report on the "Corrosion Fatigue Failure of Aircraft Control Cables (N-101)".

The attached final report, submitted by Dartrey Lewis, Technical Representative on NDRC Research Project NRC-15, has been approved by representatives of the War Metallurgy Committee in charge of the work.

This report presents the results of investigations of the physical properties of aircraft control cables under conditions of testing which were designed to reproduce service conditions, particularly those experienced by Naval Aircraft.

I recommend acceptance as the final report on the work under Contract OEMsr-492 with John A. Roebling's Sons Company.

Respectfully submitted,

Clyde Williams

Clyde Williams, Chief
War Metallurgy Division, NDRC

Enclosure

PREFACE

This report is pertinent to the problems designated by the Office of the Coordinator of Research and Development, Navy Department, as N-101, and to the project designated by the War Metallurgy Committee as NRC-15.

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FINAL REPORT

N.D.R.C. RESEARCH PROJECT NRC-15, CONTRACT NO. OEMsr-492

THE CORROSION-FATIGUE FAILURE OF AIRCRAFT CONTROL CABLES (N-101)

(From May 1, 1942 to December 31, 1944)

Work done by:
Development Engineering Laboratory
John A. Roebling's Sons Company
Trenton 2, New Jersey

Official Investigator:
Dartrey Lewis

Full Time Project Engineer:
A. H. Flury, Jr.

Report prepared by:
H. J. Godfrey

January 15, 1945

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ABSTRACT

The physical properties of aircraft control cables have been investigated under conditions of test which were designed to reproduce the effect of service conditions, particularly those experienced by Naval aircraft.

The cable sizes investigated were 1/8", 5/32", 3/16" 5/16" and 1/4" diameters with a 7x19 construction, and 3/32" diameter with a 7x7 construction. The cable materials included 18-8 Stainless Steel and Bright, Galvanized, Tinned and Lead-Alloy-Coated Carbon Steel. The galvanized cables were made of wire with various weights of hot galvanized and electro-galvanized coatings. Standard commercial cable lubricants and special lubricants containing lithium soap grease, mineral oils, paralketone neutral base, rust preventive and extra pressure additives were studied. The effect of externally applied paralketone (AN-C-52) was also investigated.

The fatigue and internal friction properties of cable as affected by corrosion in a salt atmosphere and by temperatures ranging from +160°F to -65°F were studied. The fatigue properties of cables were investigated under normal laboratory conditions with sheaves and loads similar to those used in aircraft control systems.

The fatigue tests, in which climatic conditions were investigated, were made with two fatigue machines on which the cables were loaded by dead weights equal to 1% of the specified cable strength and tested with hardened steel sheaves having diameters 9 and 12 times the cable diameter. The service load fatigue tests were made with a large testing machine on which the cables were loaded by means of hydraulic jacks. Cable loads up to 60% of the specified cable strength were used in the latter tests with AN-210 micarta and 24-ST aluminum alloy sheaves having diameters from 12.1 to 28.7 times the cable diameter.

The relative fatigue properties of aircraft cables were evaluated by an inspection of the cables for broken wires and by determining the remaining strength of the cables after various numbers of reversals on the fatigue machine.

The internal friction of the cables was determined by the load necessary to start the cable in motion over hardened steel sheaves while under various tensions ranging from 25 to 200 pounds.

The results of the fatigue tests with 1% loads showed that under the severe corrosive conditions of a salt atmosphere and at -65°F, 18-8 stainless steel cables were the most effective. Service load fatigue tests in the absence of corrosion have shown that 18-8 stainless steel cables had a considerably lower fatigue life than galvanized carbon steel cables. Heavy galvanized cables were the best of the carbon steel cables for corrosion-fatigue but had the poorest fatigue life at -65°F. The tin, lead-alloy, and light zinc coatings did not materially improve the corrosion-fatigue life of bright carbon steel cables.

The tinned cables had the lowest internal friction in the absence of corrosion. Corrosion by salt spray increased the internal friction of tinned cables and decreased the internal friction of the heavy galvanized cables. The continuous flexing of the cables during fatigue test in the absence of corrosion lowered the internal friction of the galvanized cables but not sufficiently to equal that of the tinned cables. The internal friction of cables increased with an increase in cable tension and a decrease in sheave diameter.

The fatigue and internal friction of cables were improved by the use of lubricants. The effectiveness of lubricants was dependent upon the temperature and the protection they afforded against corrosion. The commercial cable lubricants were affected considerably by temperature, whereas some of the greases performed quite uniformly over the range of temperatures investigated. Externally applied paralketone (AN-C-52), was very effective in providing protection against corrosion but became brittle at -65°F and flaked off the cable where it bent over a sheave.

The service load tests with micarta and 24-ST sheaves indicated that for a given cable tension the fatigue life was satisfactory providing the ratio between the sheave diameter and cable diameter was above a critical amount. The critical sheave ratio increased with the cable tension. For a 1% load the critical sheave ratio for 7x19 galvanized cables was approximately 10, and for 10% and 20% loads was approximately 20 and 28 respectively. The relationship between the visible wire breaks and the average loss in strength was investigated. The relationship between the loss in strength and the number of reversals in fatigue under various load conditions was also investigated for 7x19 galvanized cables.

The fatigue life of 7x7 construction cables with 1% loads was less than that of 7x19 construction with the same load and sheave ratio.

The AN-210 micarta pulleys operated satisfactorily under relatively low service loads but under higher loads failed by wear, splitting or bearing failures. The 24-ST sheaves equipped with large ball bearings operated satisfactorily under loads up to 60% of the specified cable strength.

FINAL REPORT

N.D.R.C. Research Project NRC-15, Contract No. OEMsr-492

THE CORROSION-FATIGUE FAILURE OF AIRCRAFT CONTROL CABLES (N-101)

(from May 1, 1942 to December 31, 1944)

From: John A. Roebling's Sons Company
Development Engineering Laboratory

Report prepared by: H. J. Godfrey

INTRODUCTION

This investigation on the physical characteristics of aircraft cables was undertaken by the John A. Roebling's Sons Company for the Office of Scientific Research and Development, at the request of the Navy Department. Naval experience with 18-8 stainless steel control cables had not been satisfactory due to large variations in service life. Also, as a result of the scarcity of 18-8 stainless steel, carbon steel cables had been substituted. The problem of maintaining the carbon steel cables under severe corrosive conditions was therefore considered to be acute. It was the purpose of this investigation to study the corrosion-fatigue life of cables and to develop a carbon steel cable which would be the equivalent of a stainless steel cable, particularly in a salt atmosphere. The program included internal friction tests and fatigue tests as affected by temperatures ranging from +160°F to -65°F.

The performance of control cables with loads and sheaves similar to those used in actual service conditions was also investigated for the purpose of obtaining data which would be of use in the design of aircraft control systems.

The complete details of the investigation have been reported in the following Progress Reports, which are to be considered as the Appendix to the Final Report:

Progress Report No. 1 - O.S.R.D. No. 1137, Serial No. M-31, "The Effect of Lubrication on the Fatigue Properties of Aircraft Control Cables"

" " No. 2 - O.S.R.D. No. 1525, Serial No. M-83, "The Effect of Metallic Coatings and Lubricants on the Fatigue Properties of Aircraft Cables"

" " No. 3 - O.S.R.D. No. 1610, Serial No. M-93, "The Effect of Sheave Diameter on the Fatigue Life of Aircraft Cables"

" " No. 4 - O.S.R.D. No. 3346, Serial No. M-207, "The Effect of Metallic Coatings and Lubricants on the Fatigue & Internal Friction Properties of Aircraft Cables"

" " No. 5 - O.S.R.D. No. 4543, Serial No. 439, "Aircraft Control Cables - Fatigue Tests Under Service Loads"

" " No. 6 - O.S.R.D. No. 4602 Serial No. M-452, "Miscellaneous Tests on Aircraft Cables"

The above reports should be referred to if specific details relating to this investigation are required. The final report is a summary of the work included in the progress reports and may be read without reference to the progress reports.

The investigation was carried out under the direction of an Advisory Committee, the present members of which are as follows:

Dr. L. L. Wyman, Chairman
Lt. Comdr. W. P. Goepfert, Bureau of Aeronautics, Navy Dept.
Major F. B. Fuller, Army Air Corps, Wright Field, Dayton, Ohio
Mr. J. B. Johnson, Materials Laboratory, Wright Field, Dayton, Ohio
Mr. R. R. Moore, Naval Aircraft Factory, Philadelphia, Pennsylvania
Mr. J. L. Manson, American Steel & Wire Company, New Haven, Conn.
Mr. E. S. Wellhofer, American Chain & Cable Company, Wilkesbarre, Pa.

Acknowledgement is made to Dr. J. C. Zimmer and Mr. C. W. Bohmer, Jr., and their associates at the Standard Oil Development Company Laboratories, for their assistance in developing a special lubricant for aircraft cables.

Acknowledgement is also made to Mr. C. M. Jones, Manager of Engineering, and to Mr. A. J. Morgan, Chief Engineer, Wire Rope Division, John A. Roebling's Sons Company, for their continued assistance and advice.

EXPERIMENTAL WORK

1. PROCEDURE

(a) Test Methods

Three testing machines were constructed for the cable fatigue tests. Two of these machines were designed to test in accordance with Specification AN-RR-C-43 and AN-RR-C-48, and the third machine was designed to permit the testing of cables under service loads.

A diagrammatic view of a low capacity fatigue machine is presented in Figure 1, and a photograph of a machine is shown in Figure 2. This type of machine was used to investigate cable materials and lubricants under various climatic conditions.

The corrosion-fatigue tests were made by first subjecting the cables to a 20% salt spray at 95°F for a definite period of time. They were then removed from the salt spray and while still wet, placed on a fatigue machine in a room where the humidity was maintained between 80 and 90% and the temperature approximately 75°F. Under these conditions the cables remained moist during the fatigue test. The low temperature fatigue tests were made in a cold room in which the temperature could be controlled between 70°F and -65°F. A photograph of the cold room with the fatigue machine is presented in Figure 3. The cable loads for the tests on the low capacity machines were 1% of the specified strength of the cable, as required by Specifications AN-RR-C-43 and AN-RR-C-48, and the cables were operated over hardened steel sheaves having a diameter 9 or 12 times the cable diameter.

A view of the large fatigue testing machine for the service load tests is shown in Figure 4 and a diagrammatic view of the hydraulic loading system is shown in Figure 5. The pressure on the hydraulic jacks was controlled by four Beggs Load Maintainers and the largest loading jack had a capacity of 8000 pounds. The large machine was also equipped with auxiliary apparatus by which the wrap angle could be adjusted between 0 and 90°. Except for the wrap angle tests, all of the fatigue tests on the low capacity and service load machines were made with a wrap angle of 90°. AN-210 micarta and 24-ST aluminum alloy sheaves having diameters ranging from 12.1 to 28.7 times the cable diameter were used for the service load tests.

All of the fatigue machines were equipped to test 8 cables simultaneously. Each cable operated over two test sheaves and duplicate tests were usually made for each condition of test. The fatigue life of the cables was evaluated by inspecting the cables for broken wires and by determining the remaining strength of the cables after various numbers of reversals on the fatigue machine.

The internal friction tests were conducted with hardened steel sheaves on a test frame as shown in Figure 6. The internal friction was determined with cable loads ranging from 25 to 200 pounds and the amount of load necessary to start a cable in motion was used as a measure of the relative internal friction of the cables.

(b) Materials

The cables used in this investigation included the following general types:

7x19	Preformed	Galvanized Carbon Steel
7x19	"	Tinned Carbon Steel
7x19	"	Lead Alloy Coated Carbon Steel
7x19	"	Bright Carbon Steel
7x19	"	18-8 Stainless Steel
7x7	"	Galvanized Carbon Steel

A number of sizes of cables were tested and included 3/32", 1/8", 5/32", 3/16", 1/4" and 5/16" diameters. The galvanized cables included wire hot galvanized prior to final wire drawing, hot galvanized at final size and electro-galvanized prior to final wire drawing. The cables were furnished for the investigation by the following manufacturers:

American Chain & Cable Company

American Steel & Wire Company

John A. Roebling's Sons Company

The cables were lubricated with regular commercial cable lubricants and special lubricants containing lithium soap grease, mineral oil, paralketone neutral base, rust preventives and an E.P. additive. These lubricants were either placed in the cable during manufacture or after manufacture by a special pressure fitting. The effect of externally applied paralketone (AN-C-52) was also investigated.

A list of the cable lubricants referred to in this report is as follows:

Lubricant A – Standard Commercial Cable Lubricant

Lubricant B – Standard Commercial Cable Lubricant

Lubricant C – Standard Commercial Cable Lubricant

Lubricant D – Special Low Temperature Lubricant, manufactured by Standard Oil Company, trade name "Beacon Lubricant M-285"

Lubricant H – Special Lubricant containing lithium soap grease with a base mineral oil having a viscosity of approximately 500 seconds Saybolt Universal at 100°F, and containing rust preventive and extreme pressure additives. Manufactured by Standard Oil Company of New Jersey, and designated as "Lubricant No. 5414"

Lubricant H-1 – A mixture of 5 parts of Lubricant H and 4 parts of 500 second base mineral oil containing proper proportion of rust preventive and extreme pressure additives.

Lubricant L – 45% 500-second mineral oil, plus 55% paralketone neutral base

Lubricant H was developed by the Standard Oil Development Company for this investigation.

For the service load tests, AN-210 micarta and 24-ST aluminum alloy sheaves were used. The grooves in the 24-ST sheaves conformed to AN-210 specifications but the sheaves were fitted with larger ball bearings. A view of the AN-210 micarta and 24-ST sheaves is presented in Figure 7.

2. DATA

The data has been presented in detail in Progress Reports 1 to 6. In this final report, data representing the important findings on the fatigue life and internal friction of cables has been summarized under the following headings:

a – The Effect of Materials

b – The Effect of Lubricants

c – The Effect of Load and Sheave Diameter

This data is presented in Figures 8 through 39 and in Tables I and II.

3. DISCUSSION OF RESULTS

(a) The Effect of Materials

The corrosion-fatigue life of a number of types of carbon steel cables and an 18-8 stainless steel cable is presented in Figure 8. The fatigue life without corrosion was practically the same for all cables and is represented by the dotted curve on the graph. The best corrosion-fatigue life was obtained with the 18-8 stainless steel cable and the cable made with the wire hot galvanized and drawn had the best life of any of the carbon steel cables. The weight of zinc coating on this cable was considerably more than that on any of the other galvanized cables and probably accounted for the higher corrosion-fatigue life. The bright cable had the poorest fatigue life and was not improved to any great extent by the use of tin, or light weight zinc coatings. The lead alloy coating was in one instance somewhat better than the lighter zinc coatings.

From the above results it may be assumed that the stainless steel cable is the best for operation in a salt atmosphere and would be more effective as the corrosion became more severe.

The effect of the weight of zinc coating on the corrosion-fatigue life is presented in Figure 9, where it is shown that the corrosion-fatigue life is improved by the use of a heavy zinc coating.

Photographs of 18-8 stainless steel, galvanized and tinned carbon steel cable after the corrosion-fatigue test are presented in Figures 10, 11 and 12, and illustrate the relative effectiveness of the three types of cable under fatigue when corrosion by a salt atmosphere is present.

The fatigue properties at $-65^{\circ}F$ of various types of aircraft cables are presented in Figure 13. The 18-8 stainless steel cable was considerably better than any of the carbon steel cables at this low temperature and may be due to the stainless steel maintaining its toughness at sub-zero temperatures. The heavy galvanized cable had the poorest fatigue life, which is probably the result of its high internal friction at $-65^{\circ}F$.

The effect of the weight of zinc coating on the fatigue life at $-65^{\circ}F$ is presented in Figure 14 and shows that the fatigue life decreases as the weight of galvanizing increases.

The above corrosion-fatigue and low-temperature fatigue tests were made on steel sheaves with root diameters 12 times the cable diameter and with cable loads equal to 1% of the specified cable strength. Fatigue tests on 18-8 stainless steel and galvanized carbon steel cables with sheaves and loads similar to those used in present day aircraft are presented in Figure 15. The cable tension was equal to 10% of the specified cable strength and AN-210 5A micarta sheaves having a root diameter 17-1/2 times the cable diameter were used. Under this relatively high load the fatigue life of the 18-8 stainless steel cable was considerably less than that of the galvanized carbon steel cable.

The low fatigue life of the stainless steel cable may be due to its low resistance to concentrated stresses which has been evidenced in tension tests. The 18-8 cables always show a lower tensile strength when using drum grips as compared to sockets, and break at the tangent point of the drum, whereas carbon steel cables do not show any difference in strength when tested by these two methods.

As a result of the fatigue tests on the various types of cable, the choice of cable should be determined by the conditions of service. The results of the tests indicate that if salt corrosion is of importance, 18-8 stainless steel cable should be the best cable. However, under heavy loads without corrosion, a carbon steel cable should be more effective.

The internal friction of aircraft cables was found to be affected by the type of material. Since the stresses in cables increase with an increase in the internal friction, this property has considerable influence on the fatigue life of cables. The internal friction also has a large effect on the sensitivity of the control of aircraft in flight.

The results of internal friction tests at room temperature and at -65°F are presented in Figures 16 and 17. At both conditions of test the tinned cable had the lowest internal friction. The internal friction of the galvanized cables increased as the weight of zinc coating increased and the internal friction of all the cables was considerably higher at -65°F than at room temperature. The increase in the internal friction at low temperature is due in part to the higher viscosity of the cable lubricants at this temperature. The internal friction was also proportional to the cable tension.

The internal friction of cables was found to change as they became corroded or were flexed during the fatigue tests. The effect of corrosion and fatigue are presented in Figures 18 and 19, and show that internal friction of the heavy galvanized cable was the highest as-manufactured and decreased as the period of corrosion and number of reversals increased. The internal friction of the tinned cables increased with corrosion and after

192 hours of salt spray, was equal to that of the heavy galvanized cable. The increase in the internal friction of the tinned cable was probably due to the pitting of the wires.

In the absence of corrosion the internal friction of the tinned cable during fatigue remained practically constant. The internal friction of the galvanized cable decreased somewhat during the fatigue test but was always higher than that of the tinned cable.

Where internal friction is of primary importance, the choice of cable will be influenced considerably by the expected service conditions. For normal exposure, a tinned cable would be desirable if sufficient protection could be provided against corrosion. In conditions of severe corrosion, the 18-8 stainless steel cable would probably have the lowest internal friction properties. The heavy galvanized cable would furnish protection against corrosion but would probably have the highest internal friction.

(b) The Effect of Lubricants

The results of fatigue and internal friction tests discussed above were obtained with cables lubricated with regular commercial cable lubricants. Since regular lubricants are affected to a large extent by temperature, several special lubricants were investigated for the purpose of securing one which would operate satisfactorily under all conditions.

The general effect of temperature between -65°F and +120°F on the fatigue life of aircraft cables is presented in Figure 20. These results show that regular commercial cable lubricants are best at room temperature but decrease in effectiveness with higher or lower temperatures. The special low temperature lubricant "D", however, maintained its lubricating value over the complete range of temperatures investigated. The cable with no lubricant had relatively low fatigue properties. Of the three commercial cable lubricants investigated, lubricant "A" was generally better than the two other lubricants, "B" and "C". The special lubricant, "D", maintained its consistency over a wide range of temperatures. The commercial lubricants, however, became very hard at low temperature and also tended to become fluid at high temperatures, and these characteristics were reflected in the fatigue properties of the cable.

The results of corrosion-fatigue tests on carbon steel cables with lubricants "A" and "H" are presented in Figure 21 and show a very marked improvement in corrosion-fatigue life by the use of the special lubricant "H". The value of lubricant "H" at -65°F is also demonstrated by the fatigue tests presented in Figure 22. Lubricant "H" maintained its viscosity and provided the necessary lubrication over a wide range of temperature.

Aircraft are sometimes subjected to temperatures up to 160°F, particularly when on the ground, and the effect of this high temperature on the cable lubricants was investigated. The test procedure consisted of first heating the cables to 160°F for a definite period of time and then testing on the fatigue machine under various conditions. The loss in the fatigue life due to the previous heating was found to have a relation to the amount of lubricant which drained from the cable during the heating. This relationship is shown in Figure 23 for lubricants A, H, H-1 and L. Lubricant "L" was a mixture of 45% 500 second oil plus 55% paralketone neutral base and had previously been very effective in corrosion-fatigue and low temperature fatigue tests. Lubricant "H-1" was a mixture of 4 parts of 500 second mineral oil containing the proper proportions of rust preventive and extreme pressure additives and 5 parts of lubricant "H". As lubricant "H" was a grease, it required a special pressure system to place the lubricant in the cable. Lubricant "H-1" was made so that it could be applied to the cable during manufacture in a normal manner. The above corrosion-fatigue tests show that lubricants "H" and "H-1" were the only lubricants that did not drain to any large extent from the cables when heated to 160°F. The cables with lubricants "A" and "L" had a considerably lower fatigue life after heating due to the loss of lubricant.

Fatigue tests at -65°F on cables with lubricants "H" and "L" are presented in Figures 24 and 25, and show that the previous heating to 160°F had no effect on the cables with lubricant "H" but lowered the fatigue life of the cables with lubricant "L".

The above results have shown lubricant "H" to be very effective at low temperature and with corrosion. However, AN-RR-C-43 and AN-RR-C-48 Acceptance Fatigue Tests are made at room temperature without corrosion and the performance of cables lubricated with lubricants "H" and regular commercial lubricants under these conditions of test is presented in Table I. These tests indicated that lubricant "H" was not as effective as a standard commercial lubricant but the results may have been influenced somewhat by the fact that lubricant "H" was placed in the cable after manufacture. Fatigue tests reported in Progress Report No. 6 have indicated that when lubricants are applied to cables after manufacture, the lubricant does not penetrate fully into the center of the strands and results in a lower fatigue life.

The fatigue tests showed that, in general, lubricants "H" and "H-1" are the best lubricants in atmospheric conditions similar to those encountered in service. The use of lubricant "H-1" would allow the cables to be manufactured without resorting to a special pressure system for placing the lubricant into the cables.

The effect of externally applied paralketone (AN-C-52) on the fatigue life of aircraft cables was investigated, as this material is used extensively, particularly on Naval aircraft, to protect the cables from corrosion. The results of corrosion-fatigue and fatigue tests at -65°F are presented in Figures 26 and 27 respectively. The corrosion-fatigue life of a tinned cable lubricated with a commercial lubricant was greatly improved by a coating of paralketone. At -65°F the paralketone became very brittle and flaked off when the cables were bent over the test sheaves. The value of the paralketone for its resistance to corrosion would thus be nullified if the cables were also to be operated at low temperatures.

The internal friction of aircraft cables lubricated with various lubricants was investigated under a number of conditions. The effect of temperature on a number of lubricants is illustrated in Figure 28 and shows that the internal friction of the cables with the commercial lubricants increased very rapidly when the temperature went below 0°F. The internal friction of the cable with the low temperature lubricant "D" decreased slightly as the temperature decreased, and at -65°F had the lowest internal friction of any of the lubricated cables. The cable with no lubricant had the lowest internal friction at sub-zero temperatures. Although lubricant "D" was beneficial at -65°F, it resulted in considerably higher internal friction at temperatures above zero.

Lubricant "H", which was similar in nature to lubricant "D", proved to be very satisfactory at both room temperature and at -65°F. The internal friction tests illustrating the performance of lubricant "H" and commercial lubricants at room temperature and at -65°F are presented in Figures 29 and 30 respectively. The internal friction of the cable with lubricant "H" was approximately the same at -65°F as at room temperature and was lower than any of the commercial lubricants. The internal friction of the cables containing commercial lubricants was considerably higher at -65°F.

(c) <u>The Effect of Load and Sheave Diameter</u>

The above fatigue tests, which were conducted to study the effect of materials and lubricants under various climatic conditions, were made with low cable loads. For all these tests the cable tensions were approximately 1% of the cable strength, whereas in actual service the cable loads are considerably higher. As very little data are available on the fatigue life of aircraft cables under high loads, the effect of service loads and sheaves was included in this investigation.

AN-210 micarta sheaves were used wherever possible but when these failed too rapidly, 24-ST sheaves fitted with large ball bearings were used.

An example of the effect of cable loads ranging from 10% to 60% of the cable strength is shown in Figure 31. The sheave diameter for this test was 28.7 times the cable diameter and under these conditions the cables operated satisfactorily with loads up to 20%. The fatigue life with a 40% load, however, was considerably lower. With a 60% cable tension the cables failed after relatively few numbers of reversals.

At the completion of each fatigue test the number of visible wire breaks were noted before determining the remaining strength of the cable. The results of these observations are shown in Figure 32 and also reflect the effect of cable tension on the life of the cable.

The effect of variations in the sheave diameter on the fatigue life is shown in Figure 33 for sheave ratios ranging from 16.1 to 28.7. The cable tension for these tests was 20%, and the results indicate that for this load, fatigue life was satisfactory with a sheave ratio of 28.7 but was seriously reduced with a sheave ratio of 23.4.

A large number of service load tests were conducted on 1/8", 3/16" and 1/4" diameter 7x19 galvanized cables and for each sheave size there was a critical load range below which the fatigue life of the cable was considered to be satisfactory. The effect of the sheave ratio on the critical load range is shown in Figure 34 and shows that the critical load increased with the sheave ratio. Similarly the critical sheave ratio increased as the cable tension increased and this relationship is shown in Figure 35. It should be emphasized that the critical values are not points of sudden change. However, as the critical sheave size was exceeded the cable life increased rapidly, and as the critical load was exceeded the cable life decreased rapidly. The results indicated that a satisfactory fatigue life could be obtained with a sheave ratio above 10 if the cable loads were 1%. However, with cable loads of 10% it was necessary to have a sheave ratio above 20, and with cable loads of 20%, a sheave ratio above 28 was necessary.

The life of aircraft cables in service is generally determined by an inspection for broken wires. The relationship between the number of visible wire breaks and the remaining strength of the cable is therefore of importance. The data obtained from the service load tests showed considerable scatter, particularly after the cable had a large number of wire breaks. The maximum number of wire breaks in one cable lay has been found in wire rope practice to be a good guide for judging when the cable should be removed from service. The maximum number of broken wires in one cable lay has been observed in these tests and its relation to the average loss in strength is shown in Figure 36. The actual loss in strength may be either greater or less than shown on this curve.

The data showing the relationship between the number of reversals on the fatigue machine and the remaining strength of the cable was also variable. This variation increases as the remaining strength decreases. With an average loss in strength of 10%, the tests indicated that the maximum loss in strength will, in general, not exceed 20%. With an average loss of strength in excess of 10%, the maximum loss of strength may be considerably greater. The life of aircraft cables corresponding to an average loss of strength of 10% is shown in Figure 37. This data was taken from the fatigue curves on 1/8", 3/16" and 1/4" 7x19 preformed galvanized cable. The individual points show some scatter and this should be taken into account. These curves are presented as a generalization of the information obtained and should be used only as a guide to the designer.

All of the fatigue tests discussed previously were made with a wrap angle of 90°. A limited number of tests were made on 3/16" 7x19 preformed galvanized cable in which the wrap angle ranged from 0 to 90°. The test results are presented in Figure 38 and indicate that the fatigue life decreased as the wrap angle increased from 0 to 20°. With a further increase in the wrap angle the strength of the cable after fatigue remained approximately the same as with the 20° angle tests.

The performance of aircraft cables as discussed above was obtained from tests on AN-210 micarta and 24-ST sheaves. The life of the micarta sheaves was found to be quite variable and failures occurred by wear, splitting, and bearing failures. A summary of the observations made on AN-210 micarta sheaves is presented in Table II. With the exception of the 3A sheaves, the micarta sheaves operated satisfactorily with a cable tension equal to 10% of the smallest cable used on any particular sheave. In many cases micarta sheaves did not operate satisfactorily at higher loads. As cable tension was increased the life of the micarta sheaves decreased rapidly. The 24-ST sheaves proved to be satisfactory for high cable loads.

The fatigue life of cables with 1% loads was investigated and was reported in Progress Report No. 3. The results are not reproduced in the final report but indicated that the life of 7x7 cable construction was lower than that of 7x19 construction.

Internal friction tests discussed previously have shown that the internal friction of cables was proportional to the cable tension. The effect of sheave diameter on the internal friction of cables has also been investigated and these results are presented in Figure 39. For sheave ratios between 16 and 9 the internal friction of 7x19 preformed galvanized cables increased in inverse proportion to the sheave ratio. For a sheave ratio of 7, however, the internal friction was relatively higher than at the larger sheave ratios investigated.

CONCLUSIONS

1. Under cable loads of 1%, the best cable material for use in a salt atmosphere was 18-8 stainless steel.

2. Under service loads in the absence of corrosion, the fatigue life of galvanized carbon steel cables was considerably better than that of 18-8 stainless steel cables.

3. A heavy zinc coating, either hot galvanized or electro-galvanized, gave the best corrosion-fatigue life of the various types of carbon steel cables.

4. At -65°F the 18-8 stainless steel cable had the best fatigue life and the heavy galvanized cable had the poorest fatigue life when tested with a 1% cable tension. The fatigue life of the galvanized cables at -65°F improved as the weight of zinc coating decreased.

5. The tinned cable had the lowest internal friction and the heavy galvanized cable had the highest internal friction at room temperature and at -65°F. The internal friction of the galvanized cables increased with the weight of coating.

6. The internal friction of galvanized cables decreased somewhat during fatigue testing in the absence of corrosion but remained higher than that of the tinned cable. The internal friction of the tinned cable remained constant during the fatigue test.

7. The internal friction of 18-8 stainless steel cable was not affected by salt spray corrosion whereas that of tinned cable increased and that of galvanized cable decreased.

8. Cable lubricants improve the fatigue life of cables under all conditions.

9. Commercial lubricants gave the best fatigue results at room temperature but resulted in lowered fatigue life at -65°F and +120°F.

(Continued)

Conclusions (cont.)

10. Cables containing lubricant "H" had considerably better corrosion-fatigue life and fatigue life at -65°F than cables containing commercial lubricants. The fatigue life of cables containing lubricant "H" was also better at room temperature following exposure to 160°F temperature.

11. The internal friction of cables lubricated with lubricant "H" was somewhat lower than cables with commercial lubricants at room temperature, and considerably lower at -65°F. The internal friction of cables with commercial lubricants increased considerably at temperatures below 0°F, whereas cables with lubricant "H" were practically unaffected by temperatures down to -65°F.

12. Lubricant "H" was not as effective as regular commercial cable lubricants in the AN-RR-C-43 acceptance fatigue tests. In order to obtain the best overall cable by means of special lubricants, the present specifications may have to be revised.

13. The corrosion-fatigue life of carbon steel cables was materially improved by the external application of paralketone (AN-C-52).

14. The service load fatigue tests indicated that in order to obtain long life (over 200,000 reversals) the ratio of sheave diameter to cable diameter for 7x19 preformed galvanized cable should be greater than the values shown below:

Cable Load % of Specified Cable Strength	Sheave Ratio
1	10
10	20
20	28

15. For long cable life (over 200,000 reversals) the following loads and sheave sizes were satisfactory in the service load tests:

(Continued)

Conclusions (cont.)

Cable Size	Sheave Size	Cable Load % of Specified Cable Strength
1/8" 7x19	AN-210-4A	10
3/16" 7x19	AN-210-5A	10
3/16" 7x19	AN-210-6A	20
1/4" 7x19	AN-210-6A	10

16. The serviceability of AN-210 micarta sheaves in the service load tests is shown in the following table. Sheave failure under high loads occurred by wearing, splitting and by bearing failures.

Sheave Size	Cable Load % of Specified Cable Strength	Cable Size	Life
AN-210 3A	10-20	1/8" 3/16"	Unsatisfactory
AN-210 4A	20	3/16"	Unsatisfactory
AN-210 4A	10	1/8" 3/16"	Limited
AN-210 4A	20	1/8"	Limited
AN-210 5A	10	3/16" 1/4"	Satisfactory
AN-210 6A	10	3/16" 1/4"	Satisfactory
AN-210 6A	20	3/16"	Satisfactory

17. 24-ST Aluminum alloy sheaves with large bearings operated satisfactorily with loads up to 60% of the specified cable strength.

18. The life of 7x19 preformed galvanized cables was a function of cable load and sheave diameter. The cable life for an average loss of strength of 10% was determined. (Fig. 37).

19. The fatigue life of 7x7 preformed galvanized cable was lower than that of 7x19 construction for the same sheave ratio and cable tension.

20. A limited number of tests on 3/16" 7x19 preformed galvanized cable with various wrap angles indicated that the fatigue life was reduced as the wrap angle was increased from 0 to 20°. Above 20° the wrap angle had no further effect on the fatigue life.

21. The internal friction of cables increased as the cable loads became greater and the sheave diameters became smaller.

TABLE I

AN-RR-C-43 Acceptance Fatigue Tests
On
5/32" and 1/8" 7x19 Preformed Galvanized Aircraft Cable

Material	Before Fatigue	After Fatigue	Percent Remaining Strength
	Tensile Strength (pounds)		
Reel #1			
5/32", As Manufactured	2920	2660	
Lubricant "B"	2930	2600	
Average	2925	2630	90.0
Reel #1		2125	
5/32", Cleaned &		1600	
Relubricated with		2060	
Lubricant "H"		1870	
Average		1914	65.5
Reel #2			
5/32", As Manufactured	2950	2260	
Lubricant "B"	2950	2570	
Average	2950	2415	81.8
Reel #2		2220	
5/32" Cleaned &		2310	
Relubricated with		1970	
Lubricant "H"		2145	
Average		2161	73.2
Reel #5	2270	1300	
1/8", As Manufactured	2280	1220	
Lubricant "B"		1630	
		1810	
Average	2275	1490	65.7
Reel #5		1200	
1/8", Cleaned &		1220	
Relubricated with		900	
Lubricant "H"		1060	
Average		1095	48.0

TABLE II

EFFECT OF LOAD ON FATIGUE LIFE OF AN-210 MICARTA SHEAVES

			Condition of Sheaves				Average Reversals			
Sheave Size	Cable Load lbs.	Cable Size in.	% Good	% Worn	% Split	% Bearing Failure	Good	Worn	Split	Bearing Failure
3A	200	1/8		100				50,000		
3A	400	1/8		70	30			16,000	11,000	
3A	400	3/16		40	50	10		7,000	7,000	5,000
3A	800	3/16			100				6,000	
4A	200	1/8	71	18		11	210,000	200,000		250,000
4A	400	1/8	44	9	4	43	130,000	32,000	42,000	123,000
4A	400	3/16	31	39	8	22	150,000	180,000	120,000	140,000
4A	800	3/16	26	32	32	10	60,000	50,000	50,000	50,000
5A	400	3/16	100				240,000			
5A	700	1/4	46	45	6	3	170,000	480,000	280,000	100,000
6A	400	3/16	100				240,000			
6A	800	3/16	100				250,000			
6A	700	1/4	100				280,000			

Diagrammatic View of Aircraft Cable Fatigue Machine

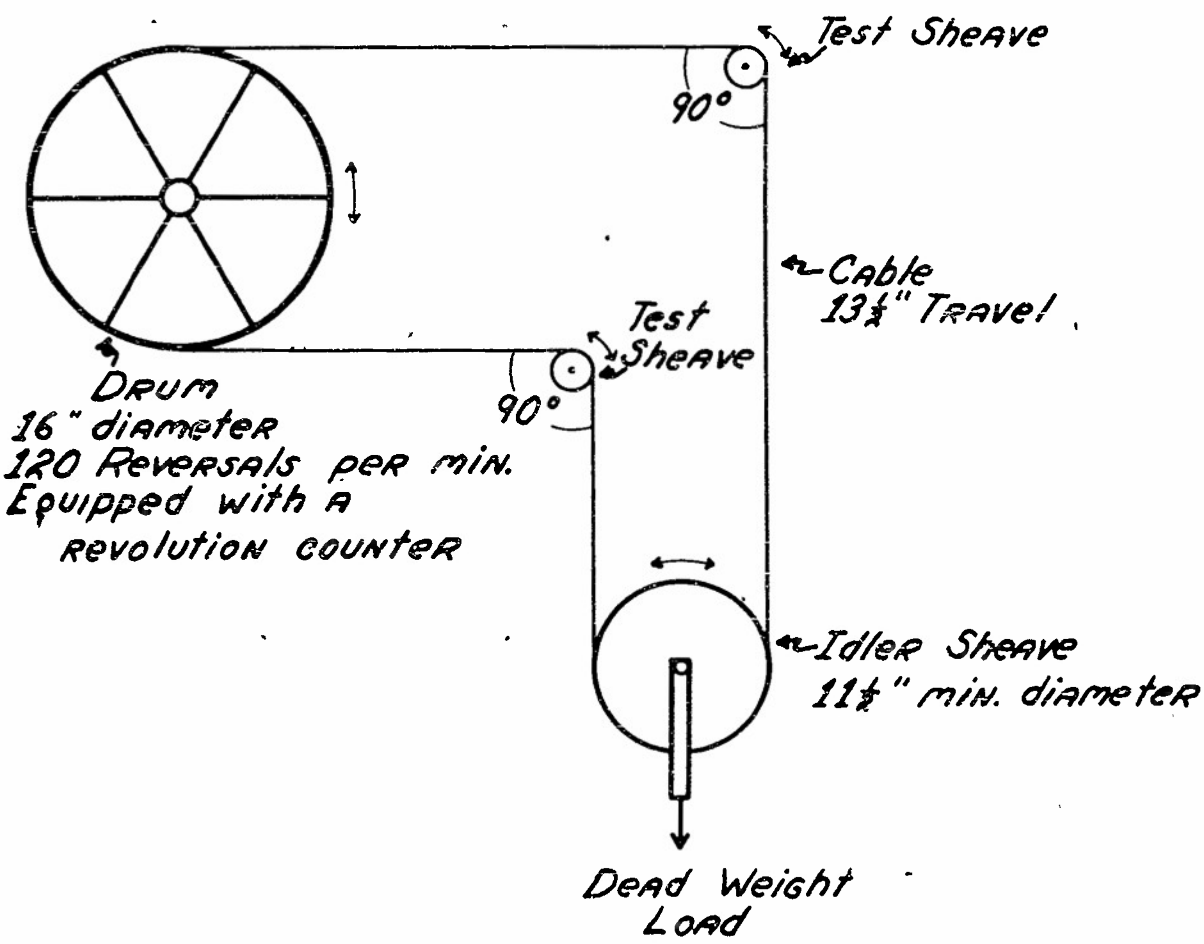


Figure 1
11-16-44
A.H. Flury, Jr.

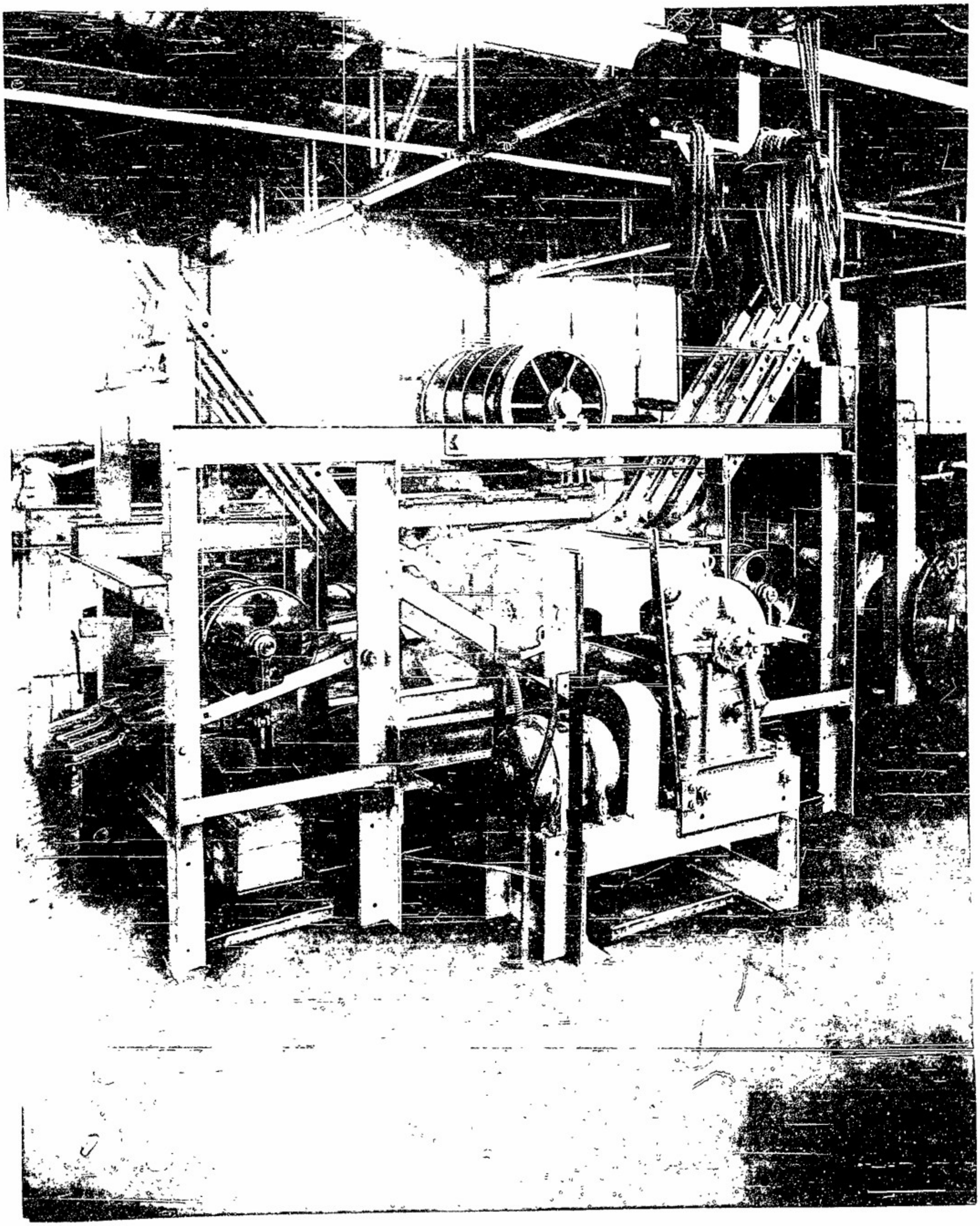


FIGURE 2

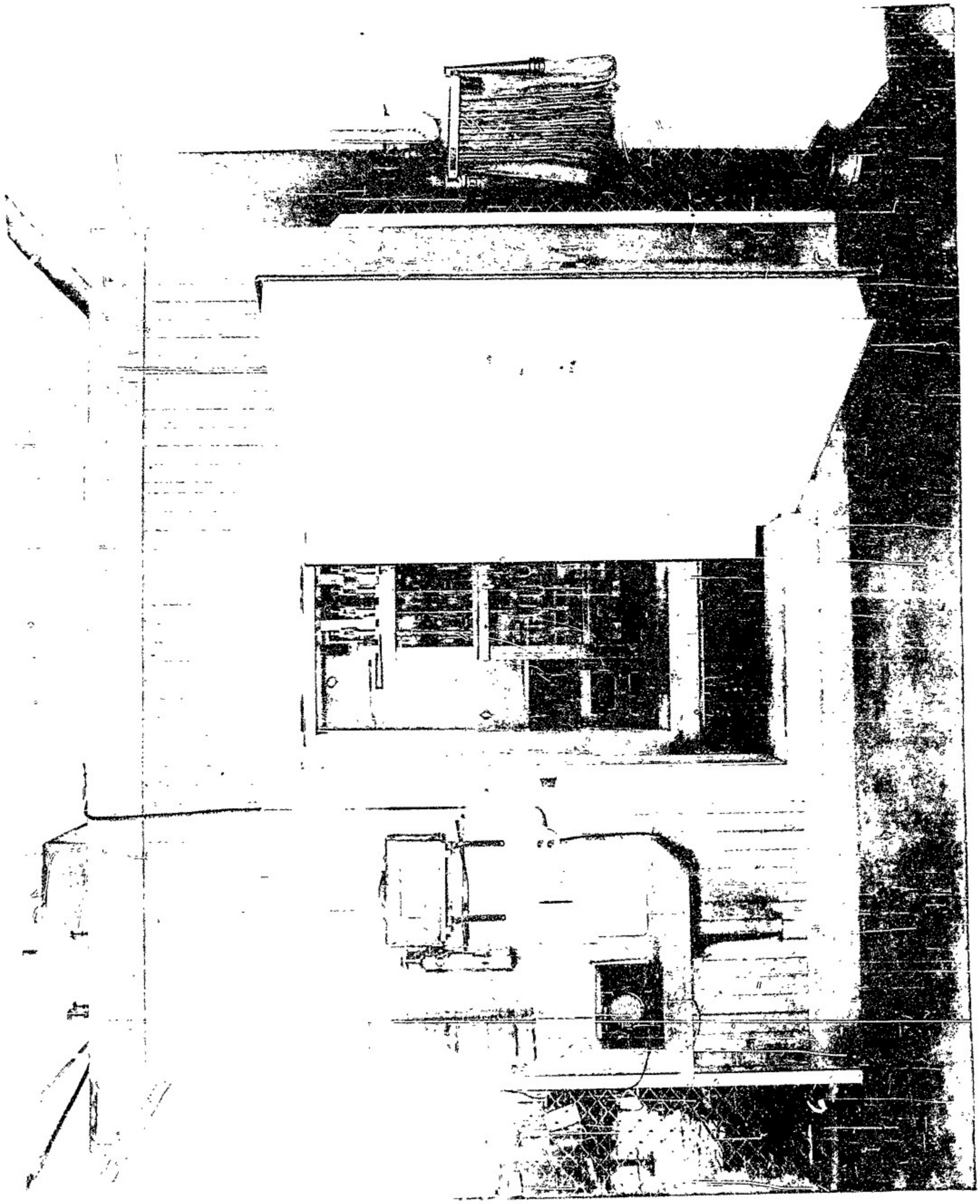
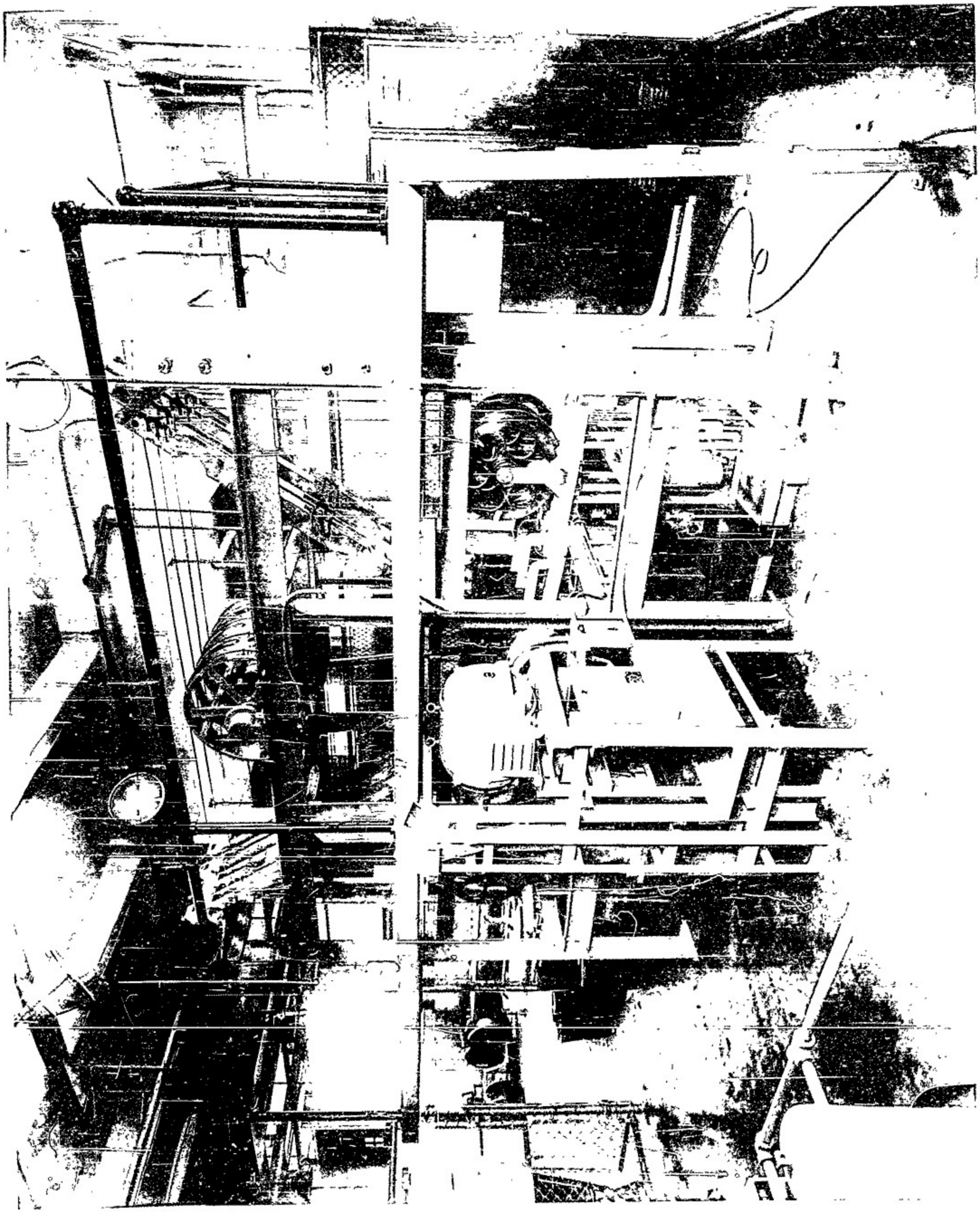


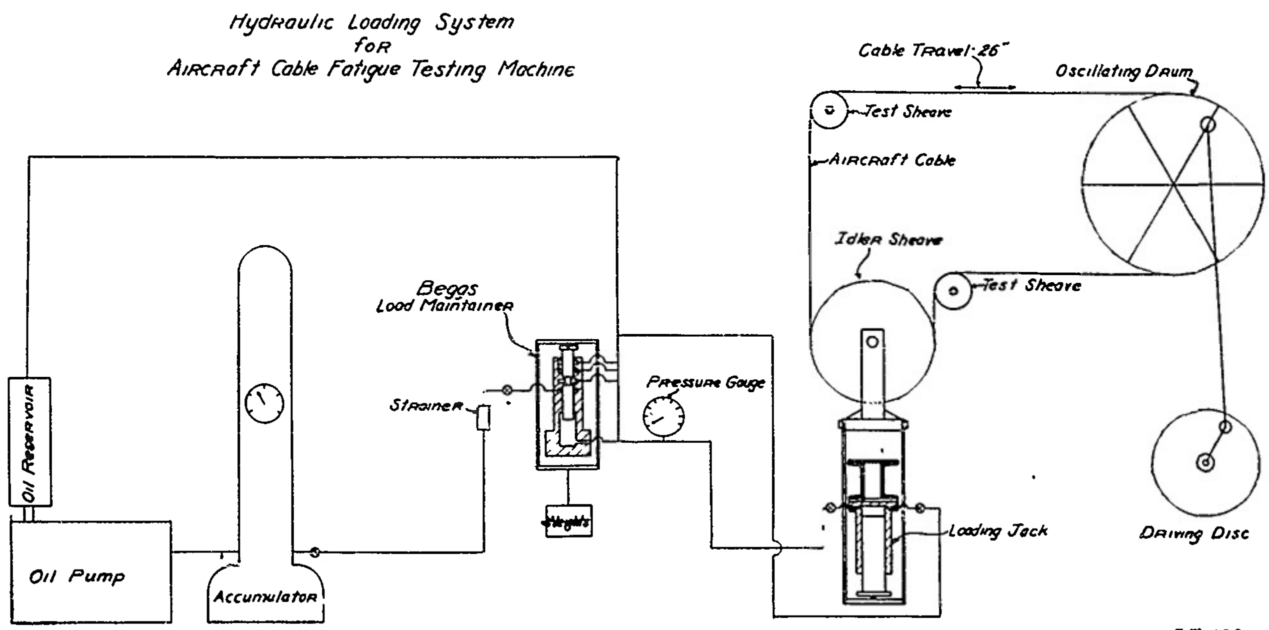
Figure 3



RESTRICTED

FIGURE 4

RESTRICTED



EI-102
Figure 5
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HIG

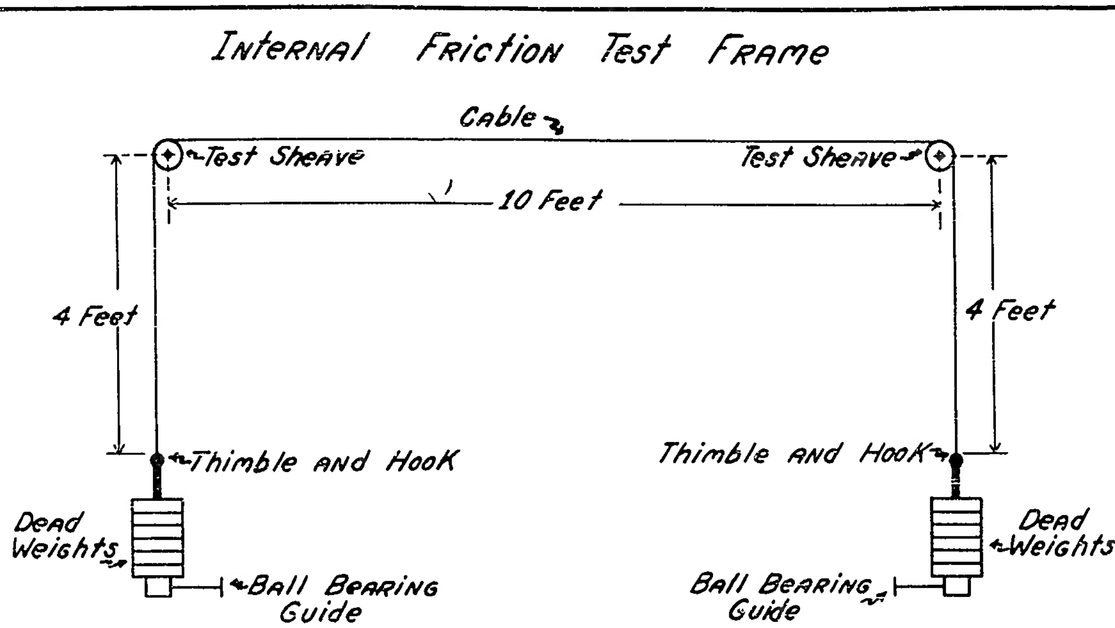


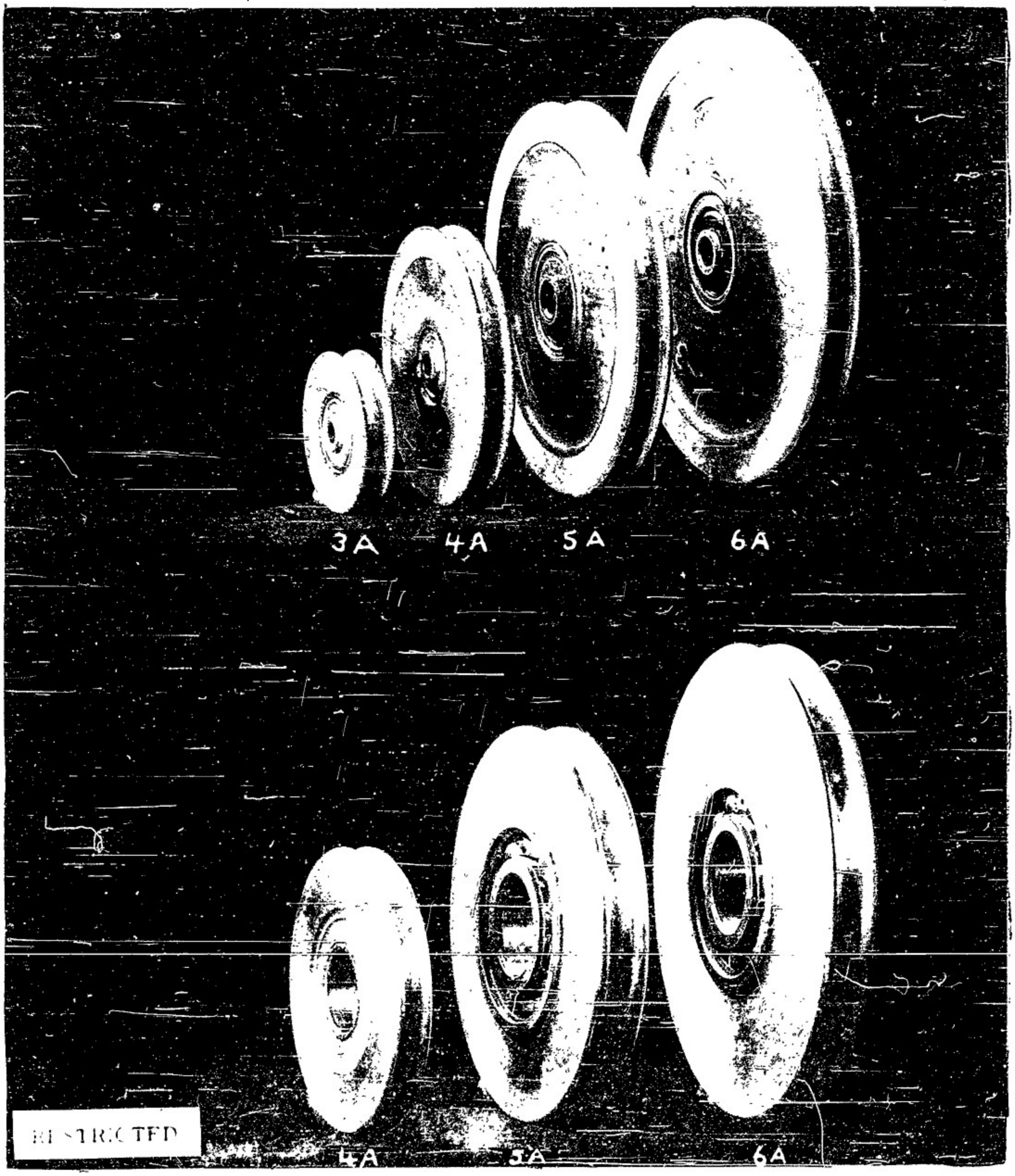
Figure 6
11-16-44
A. H. Flury, Jr.

RESTRICTED

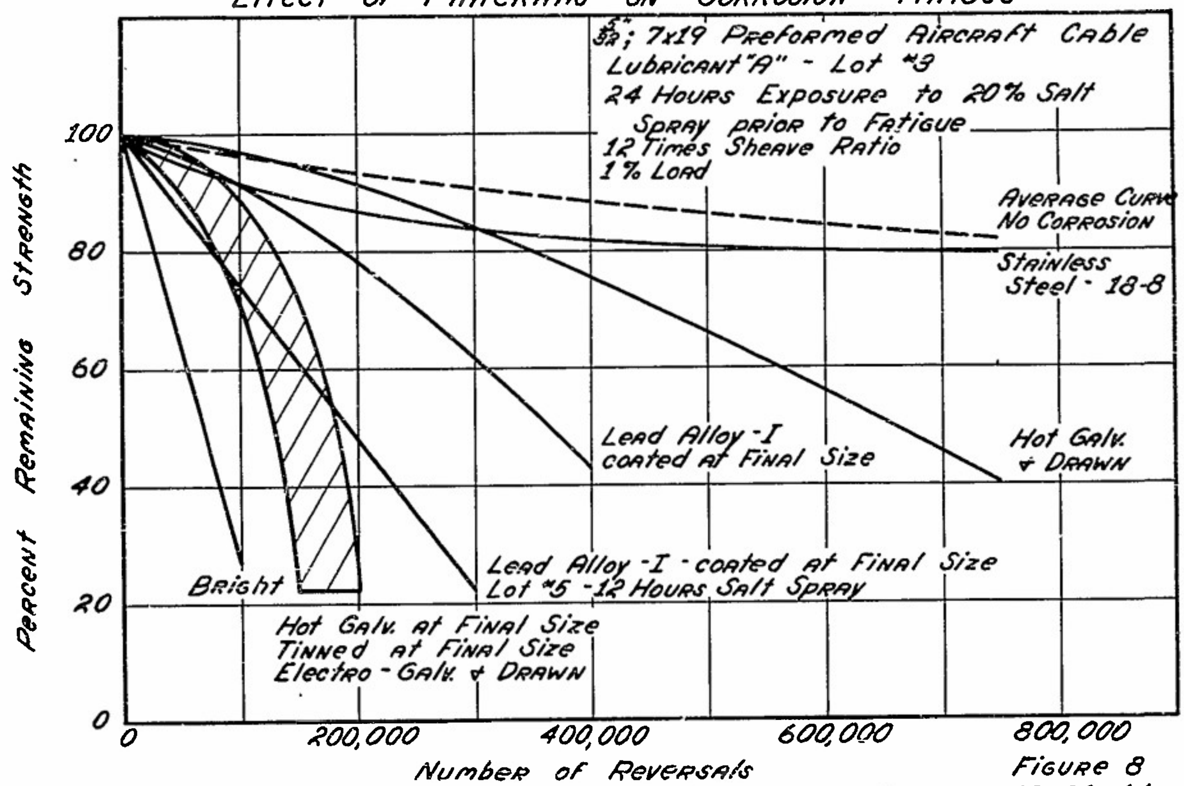
Top AN - 210 Micarta Sheaves 3A 4A 5A 6A **RESTRICTED**

Bottom 24 ST Aluminum Alloy Sheaves 4A 5A 6A

Photo #3423 10/26/44 Approx. 2/3 X *FIG. 7*



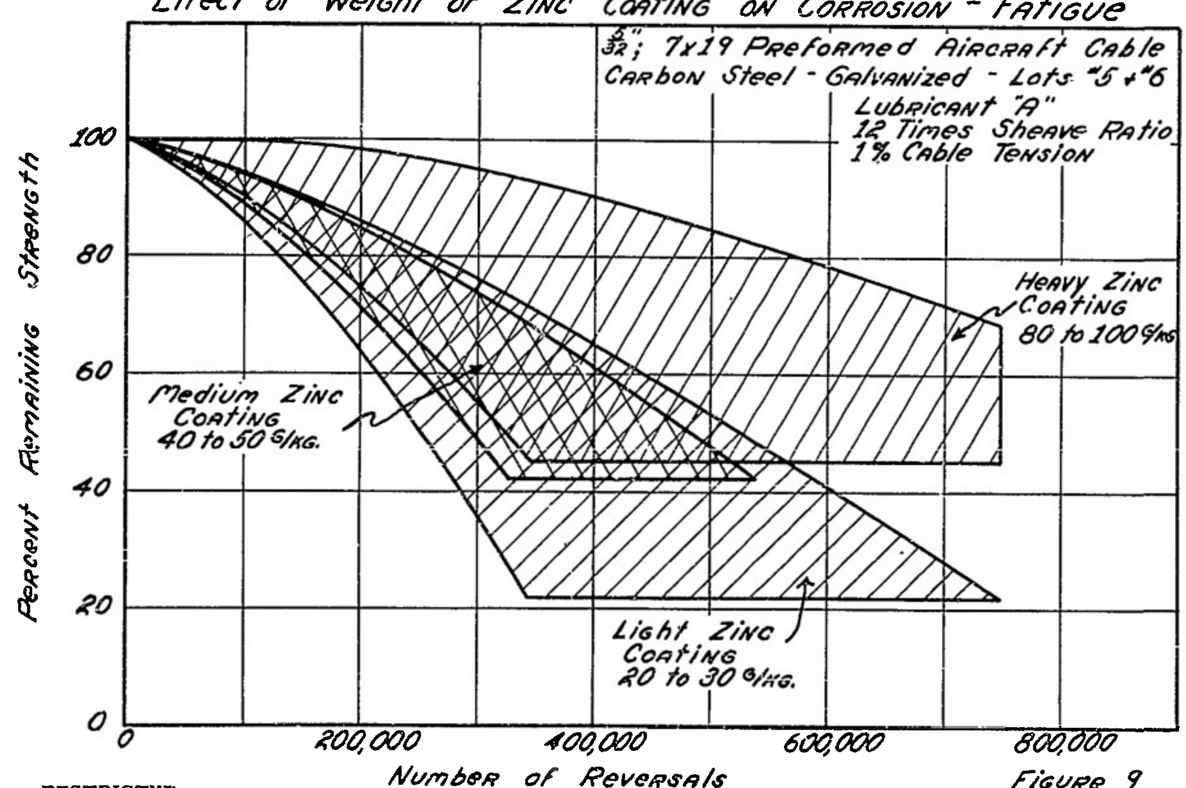
Effect of Materials on Corrosion - Fatigue



Data from Progress Report No. 2 - Figures 14 + 15
Progress Report No. 4 - Figure 5

Figure 8
12-26-44
A. H. Flury, Jr.

Effect of Weight of Zinc Coating on Corrosion - Fatigue



Data from Progress Report No. 4 - Figure 34

Figure 9
12-26-44
A. H. Flury, Jr.

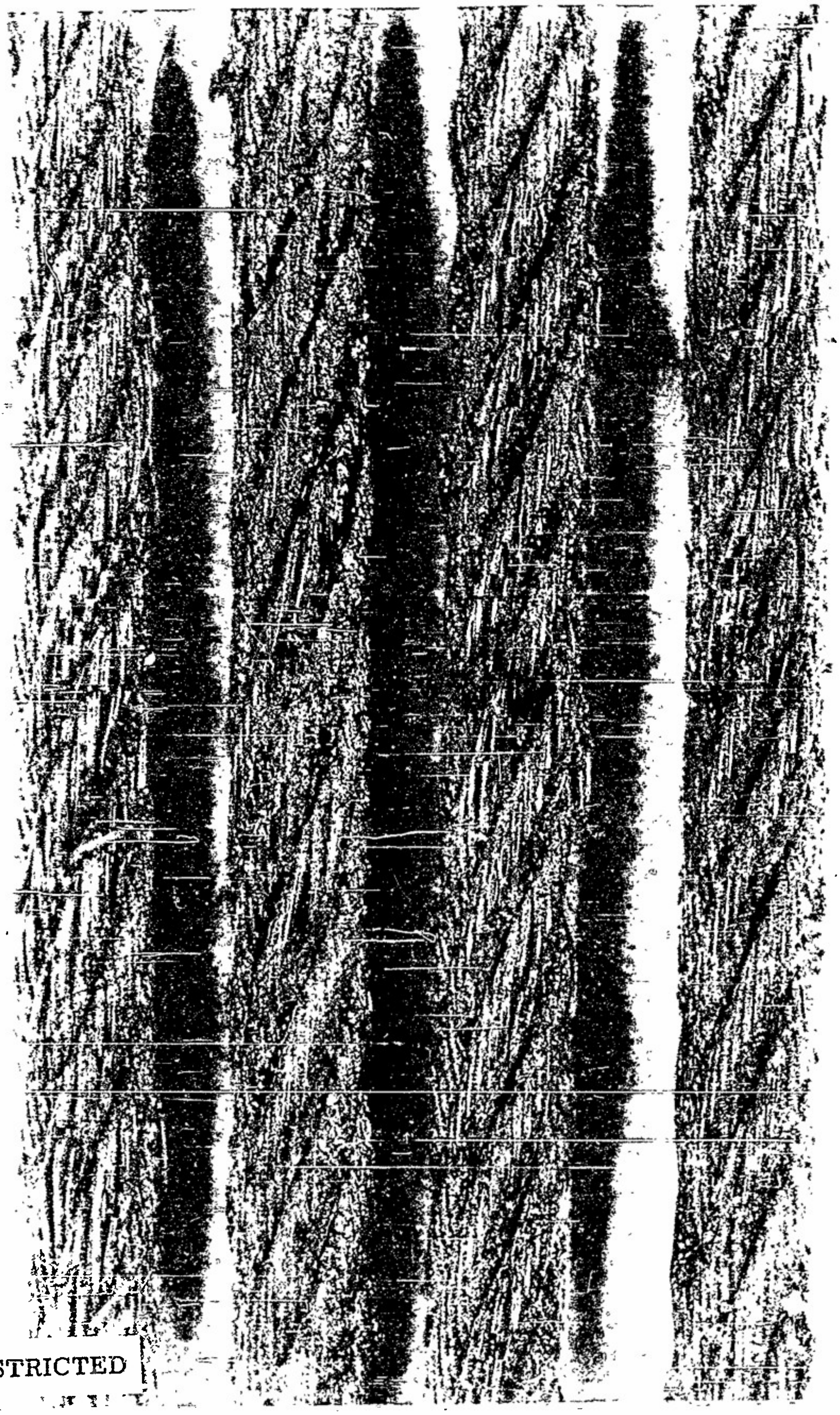
18-8 STAINLESS STEEL
12 Hours Salt Spray 750,000 Reversals--12x Sheaves. Approx. x6

Figure 10

HOT GALVANIZED AND DRAWN
12 Hours Salt Spray 750,000 Reversals--12x Sheaves.

Approx. x6

FIGURE 11.

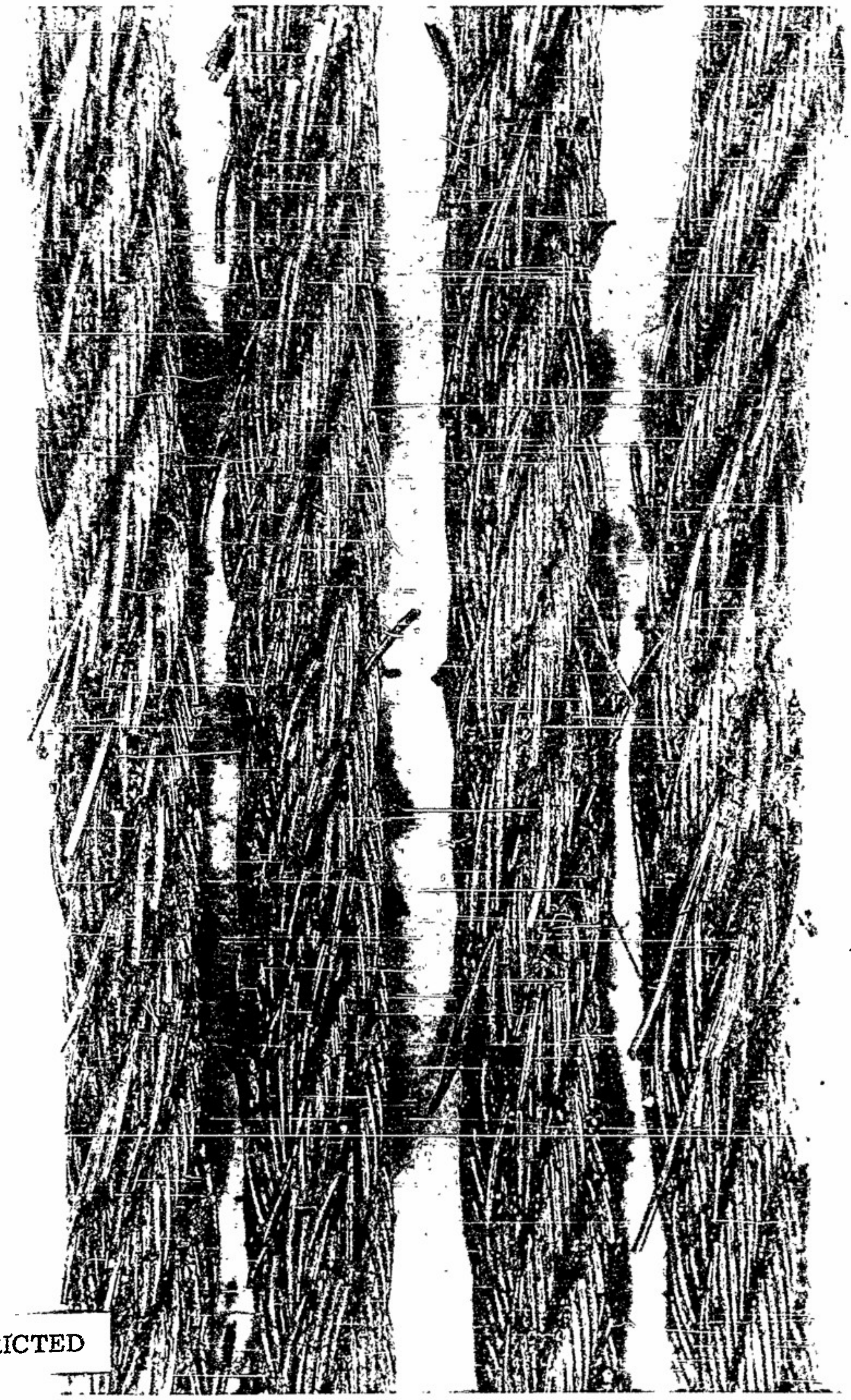


TINNED AT FINAL SIZE
12 Hours Salt Spray 300,000 Reversals--12x Sheaves.

RESTRICTED

Approx. x6

Figure 12



RESTRICTED

Effect of Materials on Fatigue at -65°F.

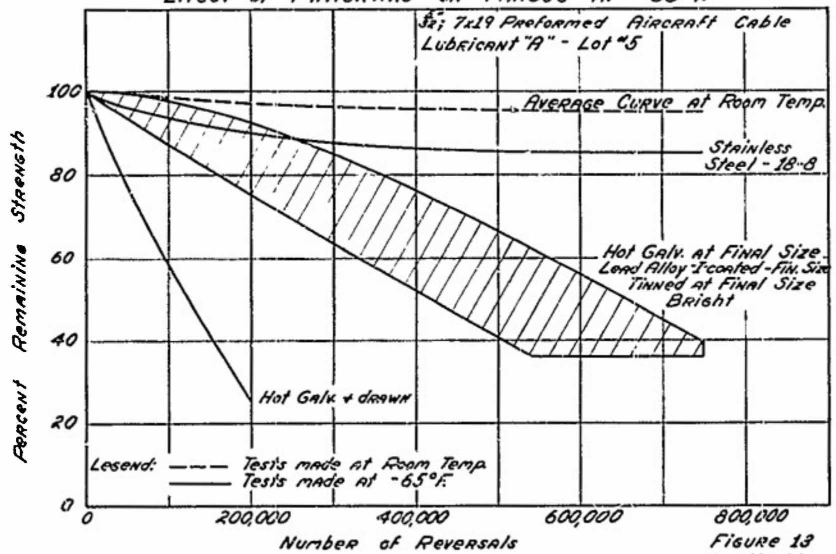


Figure 13
12-18-44
A.H. Flury, Jr.

Data from Progress Report No. 4 - Figures 3 + 7

Stainless and Carbon Steel at Service Loads

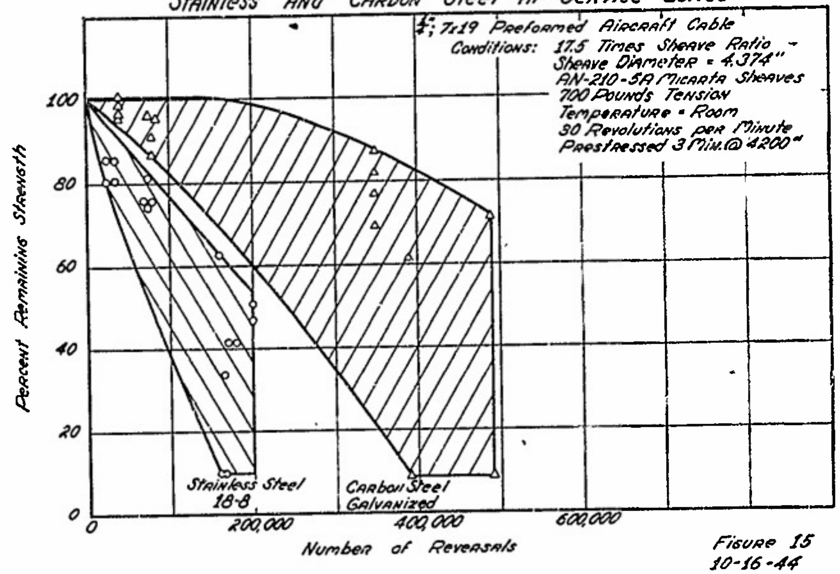


Figure 15
10-16-44
A.H. Flury, Jr.

Data from Progress Report No. 5 - Figure 67

Effect of Weight of Zinc Coating on Fatigue at -65°F.

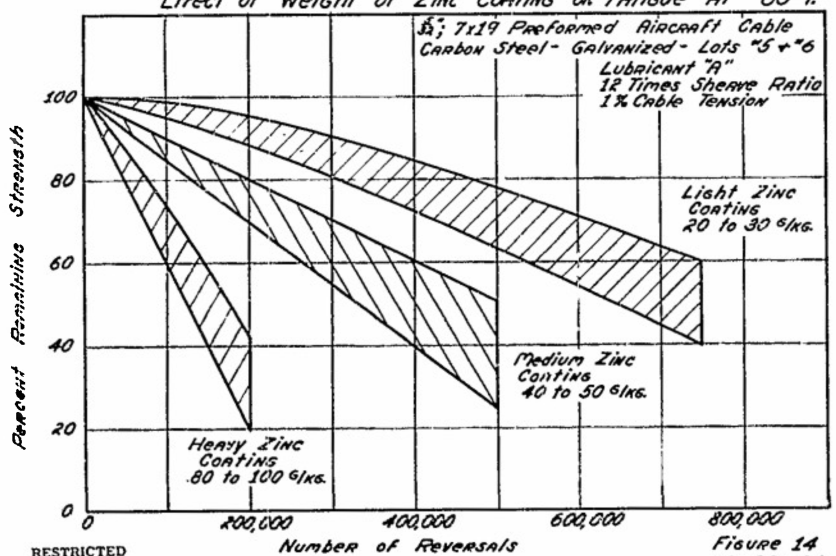


Figure 14
12-26-44
A.H. Flury, Jr.

Data from Progress Report No. 4 - Figure 32

Internal Friction Tests at Room Temperature

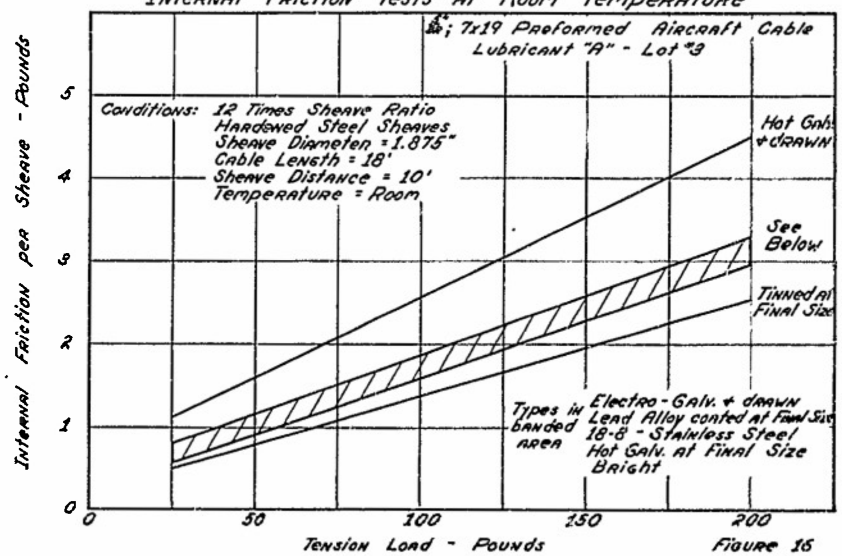
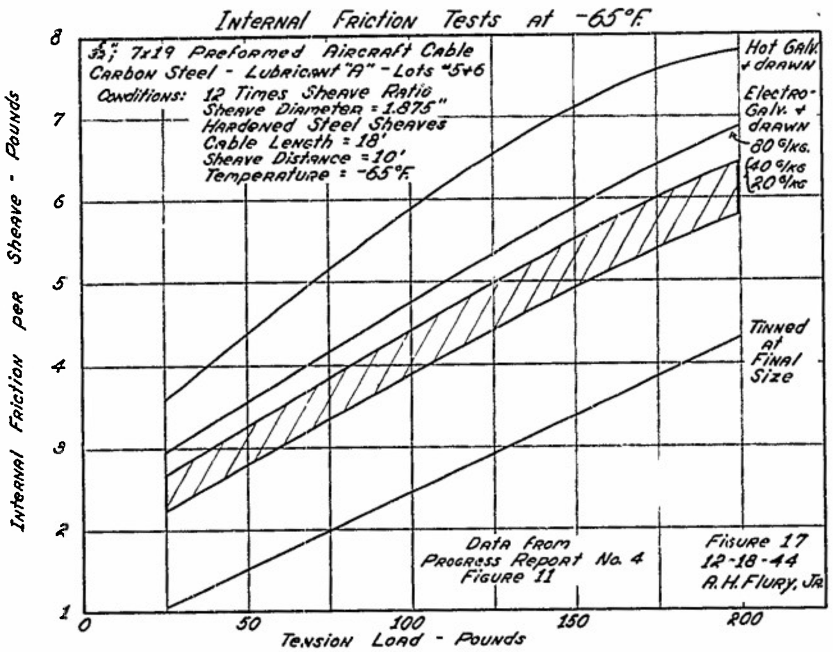
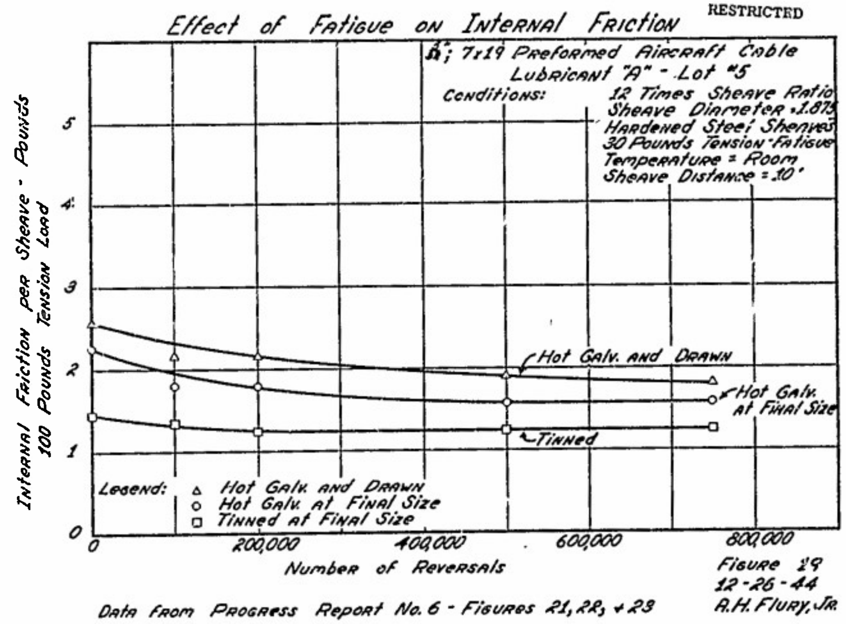
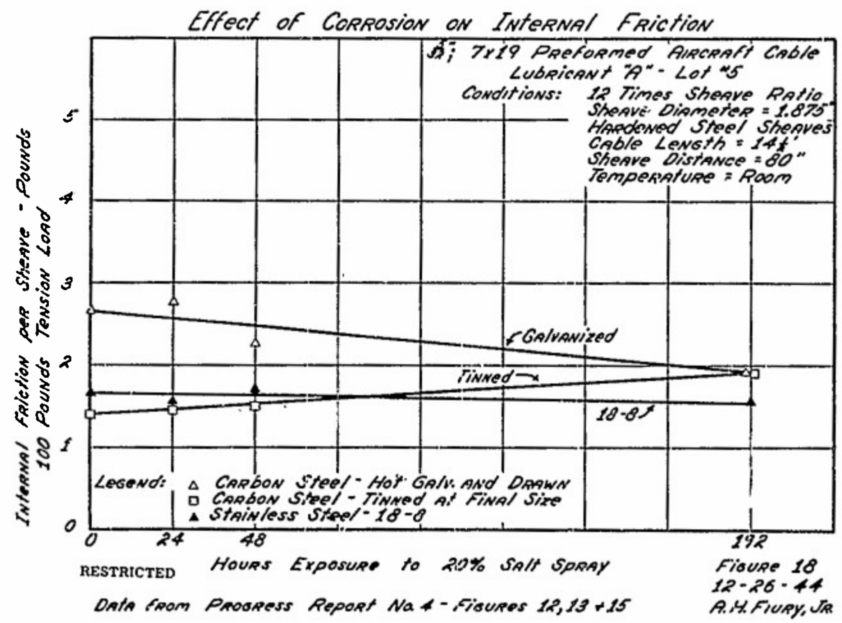


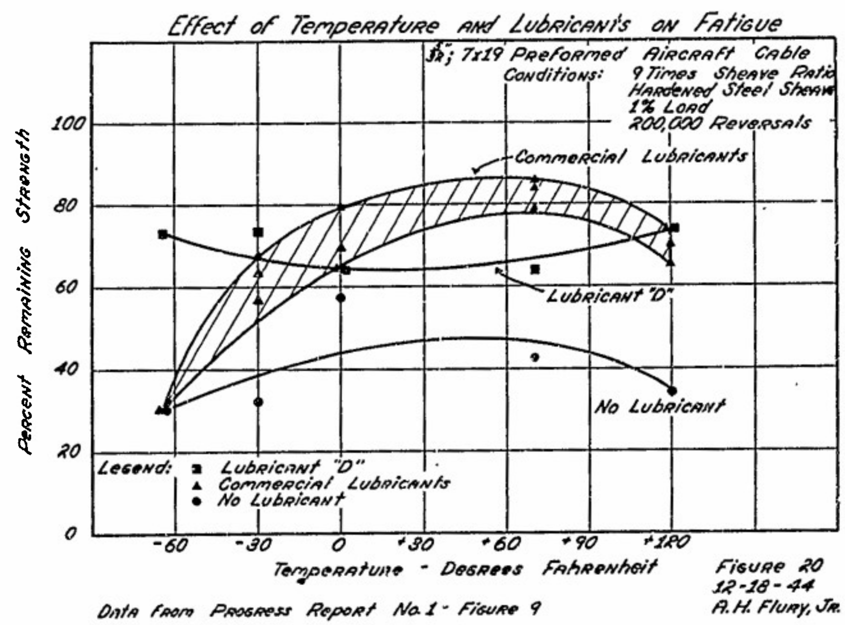
Figure 16
12-18-44
A.H. Flury, Jr.

Data from Progress Report No. 2 - Figure 29


Internal Friction Tests at -65°F.
3/32"; 7x19 Preformed Aircraft Cable
Carbon Steel - Lubricant "A" - Lots #5+6
Conditions: 12 Times Sheave Ratio
Sheave Diameter = 1.875"
Hardened Steel Sheaves
Cable Length = 18'
Sheave Distance = 10'
Temperature = -65°F.
Hot Galv. + Drawn
Electro-Galv. + Drawn
80 #/kg.
40 #/kg
20 #/kg
Tinned at Final Size
Internal Friction per Sheave - Pounds
Tension Load - Pounds
Data From Progress Report No. 4 Figure 11
Figure 17
12-18-44
A.H. Flury, Jr.


Effect of Fatigue on Internal Friction
1/8"; 7x19 Preformed Aircraft Cable
Lubricant "A" - Lot #5
Conditions: 12 Times Sheave Ratio
Sheave Diameter = 1.875
Hardened Steel Sheaves
30 Pounds Tension-Fatigue
Temperature = Room
Sheave Distance = 10'
Hot Galv. and Drawn
Hot Galv. at Final Size
Tinned
Legend: △ Hot Galv. and Drawn
○ Hot Galv. at Final Size
□ Tinned at Final Size
Internal Friction per Sheave - Pounds
100 Pounds Tension Load
Number of Reversals
Figure 19
12-26-44
A.H. Flury, Jr.
Data From Progress Report No. 6 - Figures 21, 22, + 23


Effect of Corrosion on Internal Friction
1/8"; 7x19 Preformed Aircraft Cable
Lubricant "A" - Lot #5
Conditions: 12 Times Sheave Ratio
Sheave Diameter = 1.875"
Hardened Steel Sheaves
Cable Length = 14 1/2'
Sheave Distance = 80"
Temperature = Room
Galvanized
Tinned
18-8
Legend: △ Carbon Steel - Hot Galv. and Drawn
□ Carbon Steel - Tinned at Final Size
▲ Stainless Steel - 18-8
Internal Friction per Sheave - Pounds
100 Pounds Tension Load
Hours Exposure to 20% Salt Spray
Figure 18
12-26-44
A.H. Flury, Jr.
Data from Progress Report No. 4 - Figures 12, 13 + 15


Effect of Temperature and Lubricants on Fatigue
1/8"; 7x19 Preformed Aircraft Cable
Conditions: 9 Times Sheave Ratio
Hardened Steel Sheaves
1% Load
200,000 Reversals
Commercial Lubricants
Lubricant "D"
No Lubricant
Legend: ■ Lubricant "D"
▲ Commercial Lubricants
● No Lubricant
Percent Remaining Strength
Temperature - Degrees Fahrenheit
Figure 20
12-18-44
A.H. Flury, Jr.
Data from Progress Report No. 1 - Figure 9

Effect of Lubricants on Corrosion - Fatigue

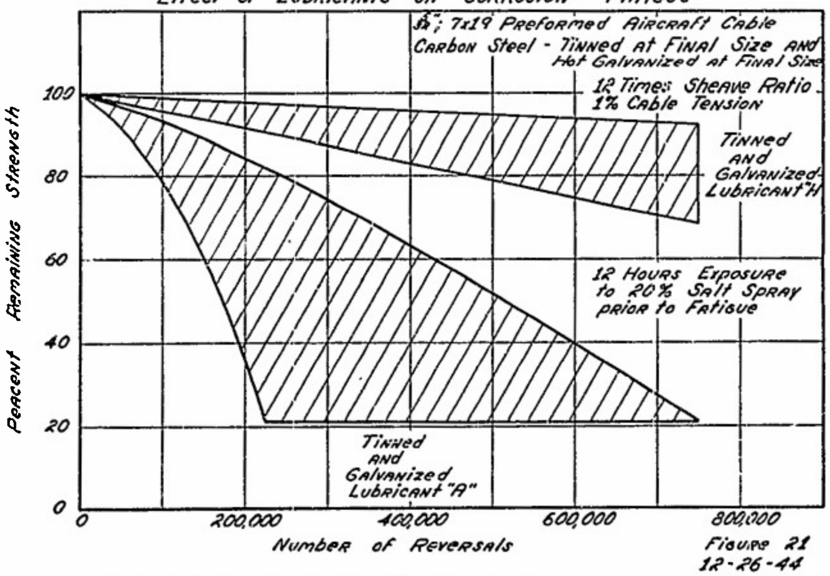
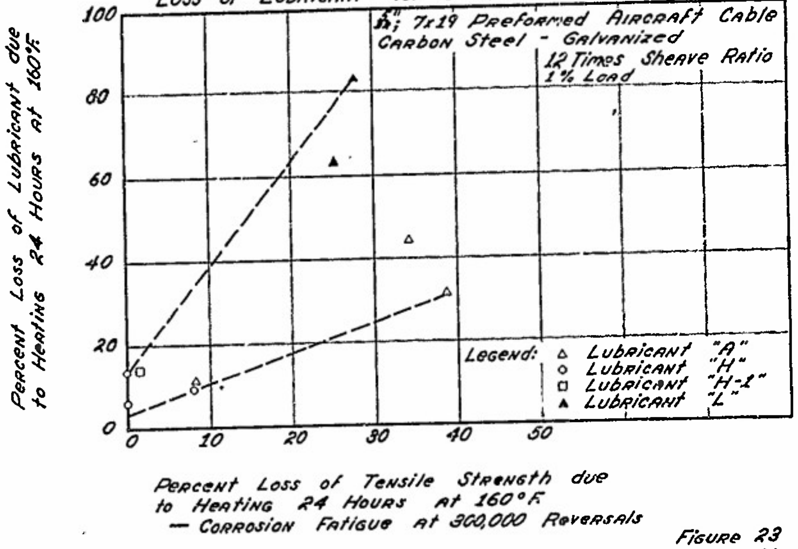


Figure 21
12-26-44
A. H. Flury, Jr.

Data from Progress Report No. 4 - Figure 36

Loss of Lubricant vs. Corrosion - Fatigue



Percent Loss of Tensile Strength due to Heating 24 Hours at 160°F. — Corrosion Fatigue at 300,000 Reversals

Figure 23
12-18-44
A. H. Flury, Jr.

Data from Progress Report No. 6
Figures 7, 8, 9, 13, 14, 15, 16 + 17

Effect of Lubricants on Fatigue at −65°F.

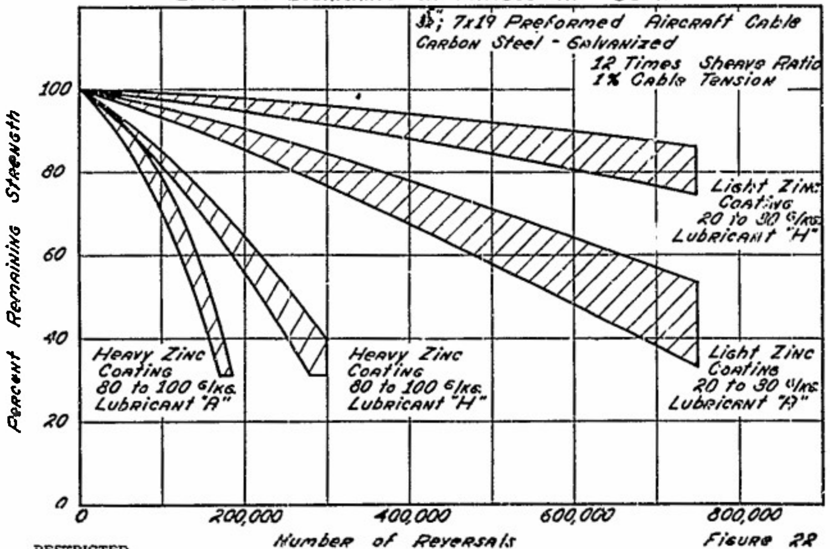


Figure 22
12-26-44
A. H. Flury, Jr.

Data from Progress Report No. 4 - Figure 35

Effect of Heating to 160°F. on Fatigue at −65°F.

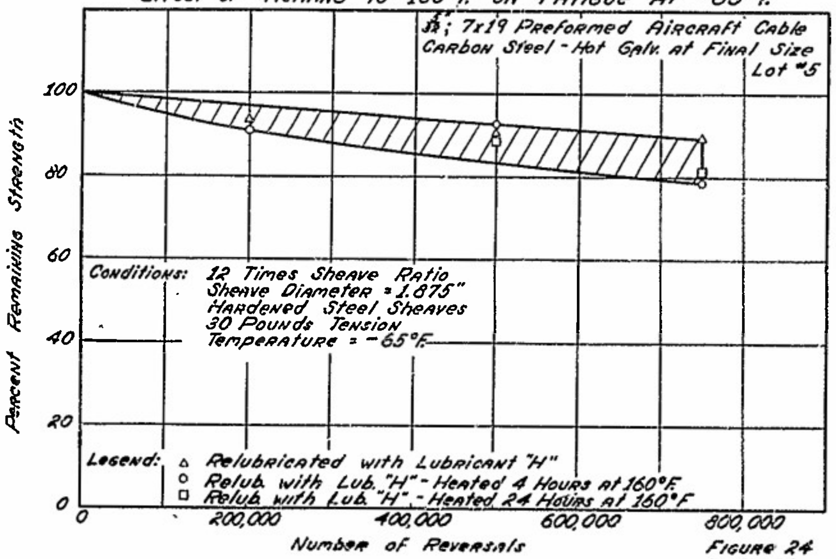
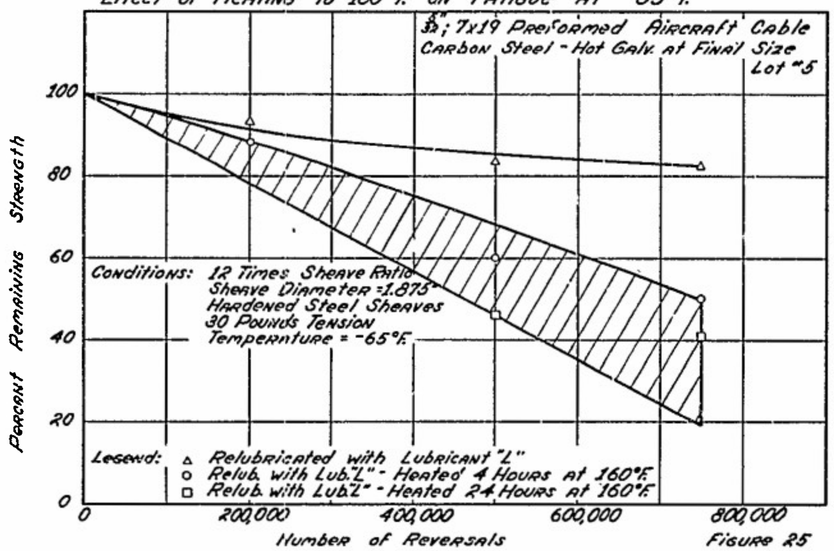


Figure 24
1-2-45
A. H. Flury, Jr.

Data from Progress Report No. 6 - Figure 11

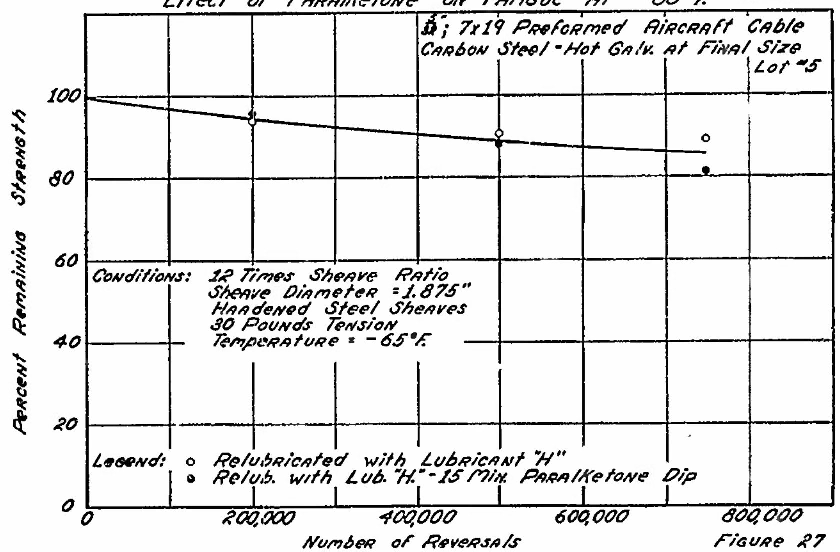
Effect of Heating to 160°F. on Fatigue at -65°F.



Data from Progress Report No. 6 - Figure 12

Figure 25
1-2-45
A.H. Flury, Jr.

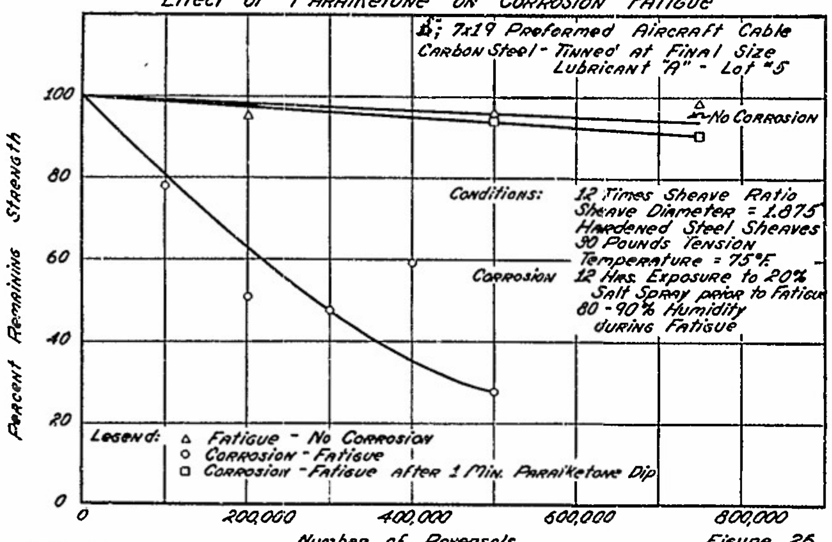
Effect of Paralketone on Fatigue at -65°F.



Data from Progress Report No. 6 - Figure 20

Figure 27
1-2-45
A.H. Flury, Jr.

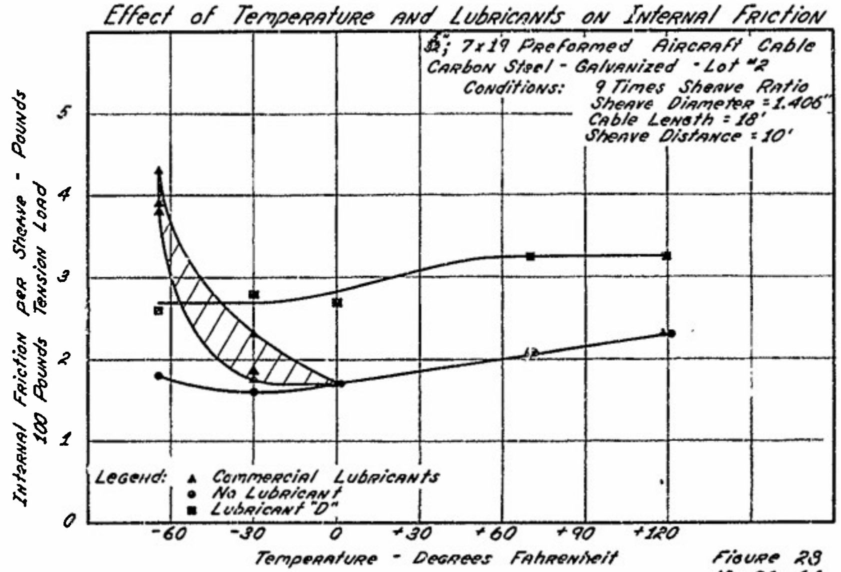
Effect of Paralketone on Corrosion Fatigue



Data from Progress Report No. 4 - Figure 26

Figure 26
12-26-44
A.H. Flury, Jr.

Effect of Temperature and Lubricants on Internal Friction



Data from Progress Report No. 1 - Figure 15

Figure 28
12-26-44
A.H. Flury, Jr.

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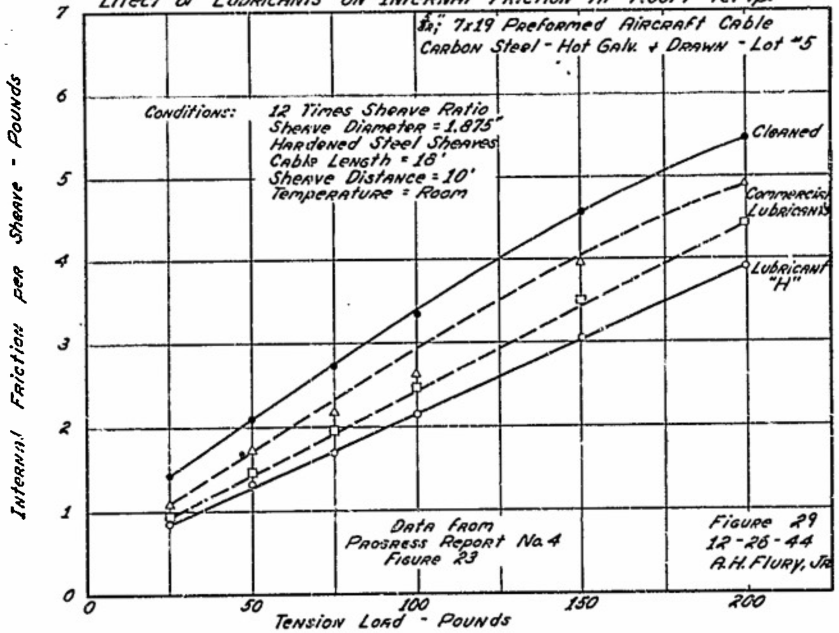
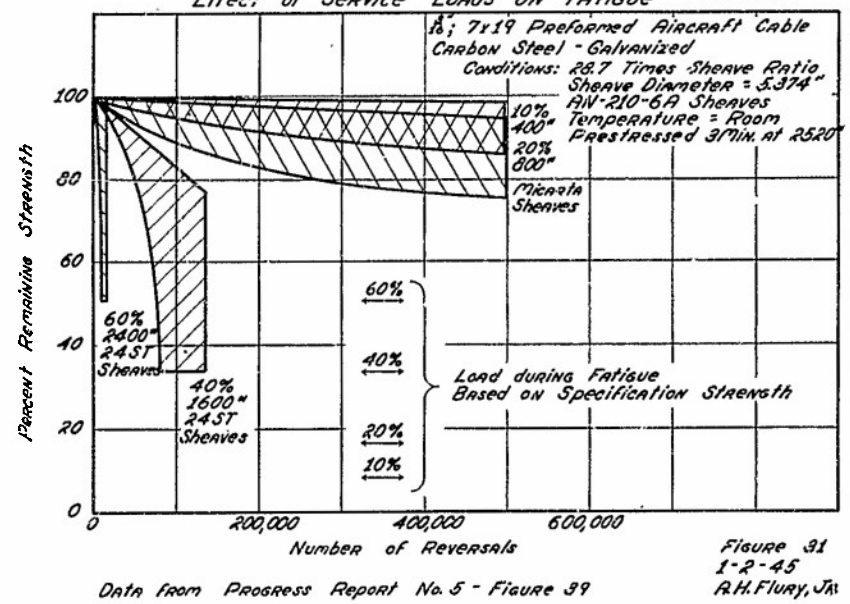
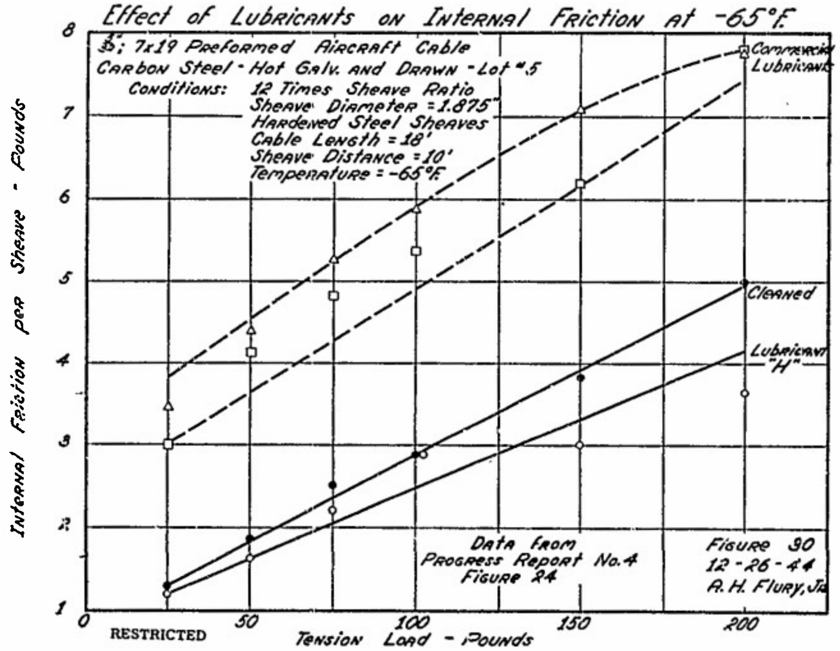
Effect of Lubricants on Internal Friction at Room Temp.



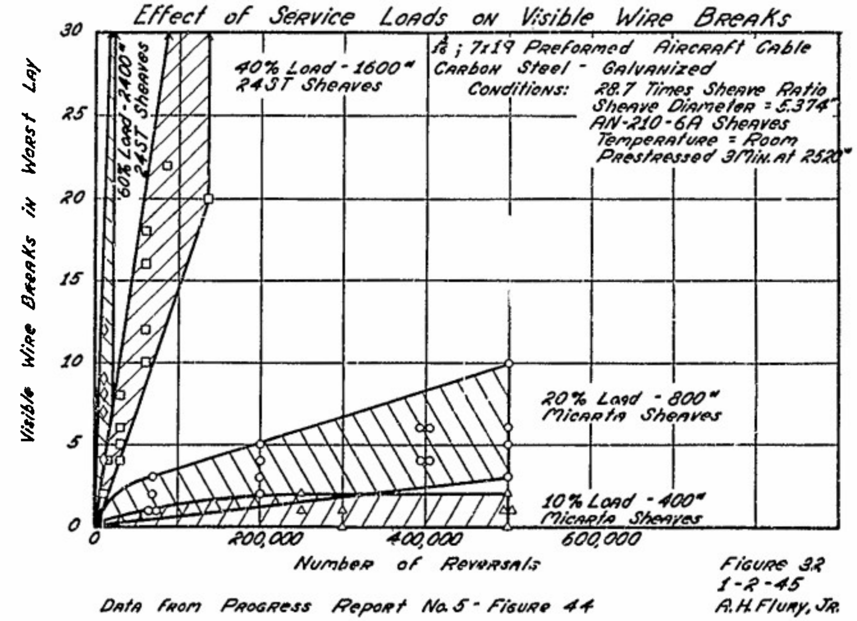
Effect of Service Loads on Fatigue



Effect of Lubricants on Internal Friction at -65°F.

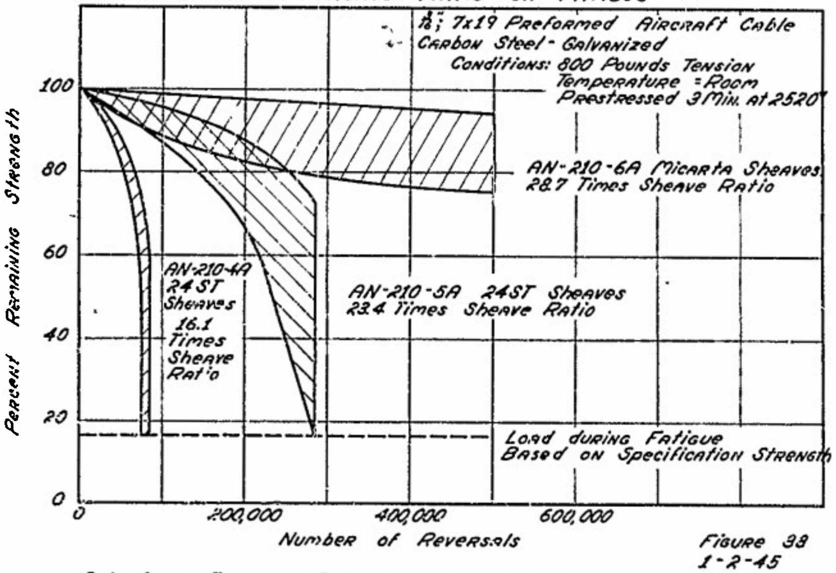


Effect of Service Loads on Visible Wire Breaks



RESTRICTED

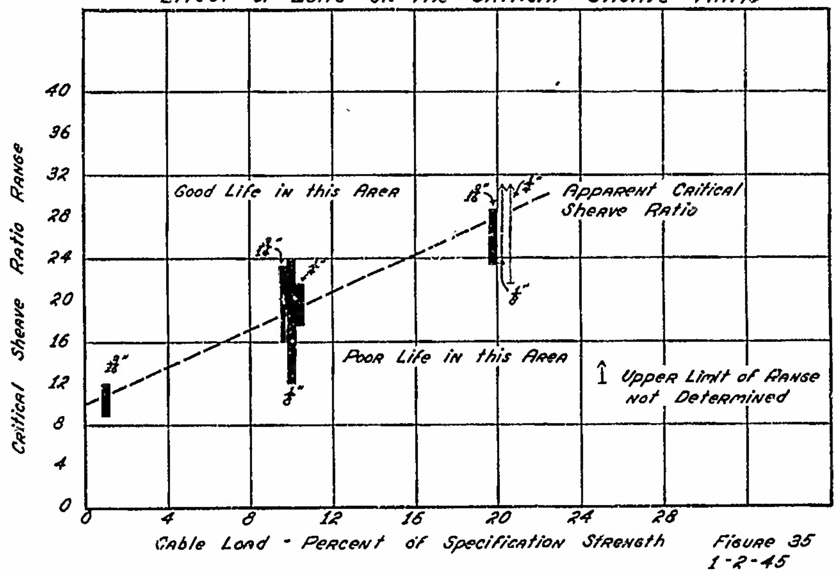
Effect of Sheave Ratio on Fatigue



Data from Progress Report No. 5 - Figure 41

Figure 38
1-2-45
A.H. Flury, Jr.

Effect of Load on the Critical Sheave Ratio



Data from Progress Report No. 5 - Figure 74

Figure 35
1-2-45
A.H. Flury, Jr.

Effect of Sheave Ratio on the Critical Load

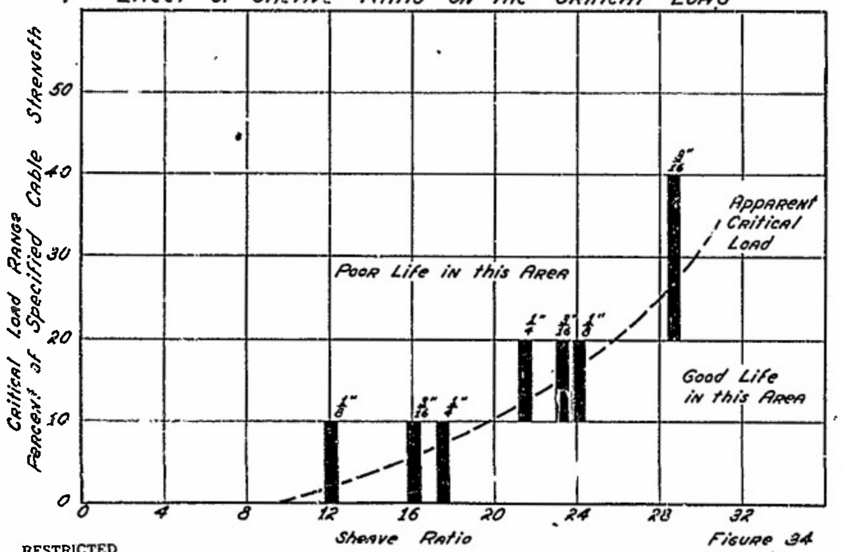
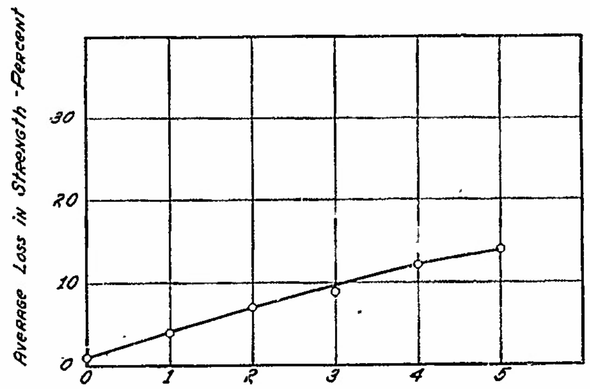


Figure 34
1-2-45
A.H. Flury, Jr.

Data from Progress Report No. 5 - Figure 73

Visible Wire Breaks vs. Cable Strength



for
7x19 Preformed Galvanized Aircraft Cable
at 10 and 20% Loads

Data from Progress Report No. 5 - Figure 81

Figure 36
1-2-45
A.H. Flury, Jr.

Life of 7x19 Preformed Galv Aircraft Cable

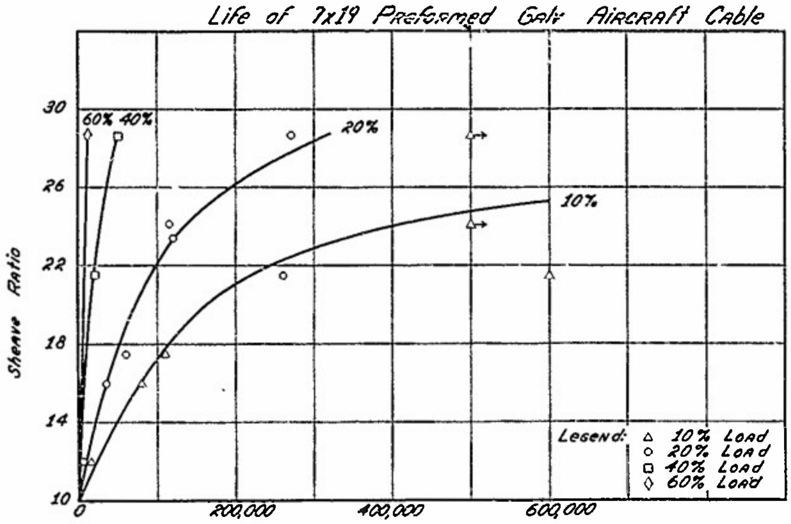


Figure 37
1-2-45
Data from Progress Report No. 5 - Figure 82
A. H. Flury, Jr.

Effect of Wrap Angle on Fatigue

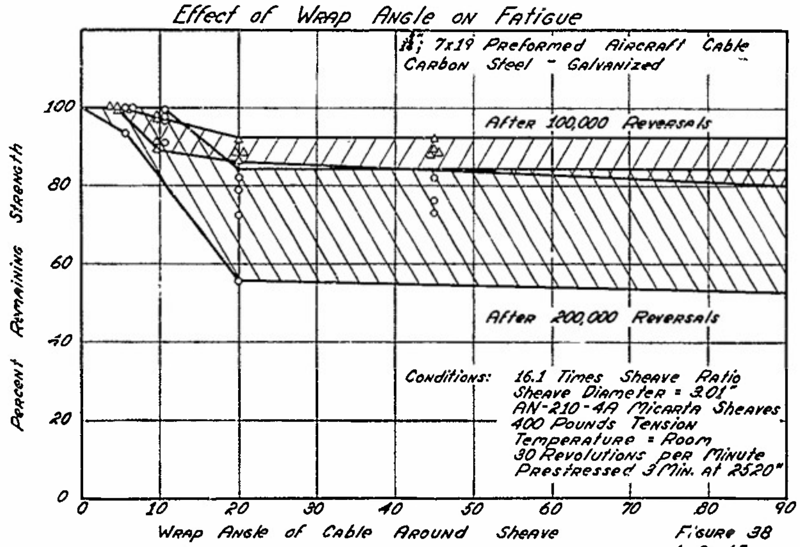


Figure 38
1-2-45
Data from Progress Report No. 5 - Figure 69
A. H. Flury, Jr.

Effect of Load and Sheave Ratio on Internal Friction

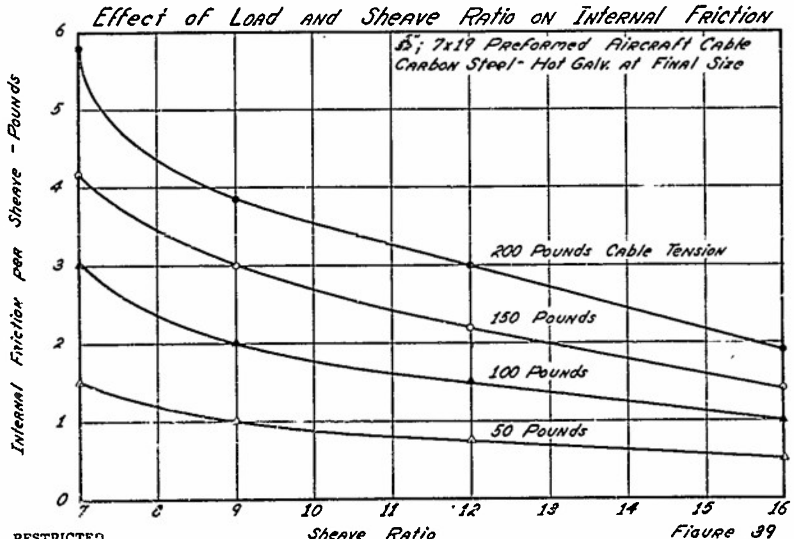


Figure 39
1-2-45
Data from Progress Report No. 3 - Figure 11
A. H. Flury, Jr.

REEL – C
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TSDIN FORM 69 A (13 MAR 47)

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P-7-4-13

ATI- 20593

Lewis, D.
Flury, A. H.
Godfrey, H. J.

AUTHOR(S)

DIVISION: Stress Analysis and Structures (7)

SECTION: Structural Testing (4)

CROSS REFERENCES: Cables, Aircraft control - Fatigue failure (14701.2)

ORIG. AGENCY NUMBER

O.S.R.D. 4819

REVISION

AMER. TITLE: The corrosion-fatigue failure of aircraft control cables (N-101)

P1/2 Aircraft Control Cables

FORG'N. TITLE:

Corrosion

over

U

ORIGINATING AGENCY: O.S.R.D., N.D.R.C., Div. 18, Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Restr.	Feb '45	60		photos, tables, diagr, graphs

ABSTRACT

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Apr. 8-12, 1946

TSDIN FORM 69 A (13 MAR 47)

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ATI- 20593

AUTHOR(S)		ORIG. AGENCY NUMBER
Lewis, D. Flury, A. H. Godfrey, H. J.	DIVISION: Stress Analysie and Structures (7) SECTION: Structural Testing (4) CROSS REFERENCES: Cables, Aircraft control - Fatigue failure (14701.2)	O.S.R.D. 4819 REVISION

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